3/17/65
b

AN INVESTIGATION OF HANDEDNESS

AND ITS RELATION TO JOB PERFORMANCE

A THESIS

Presented to

The Faculty of the Graduate Division

by

Philip Davis Kelley

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Industrial Engineering

Georgia Institute of Technology

March, 1968

AN INVESTIGATION OF HANDEDNESS

AND ITS RELATION TO JOB PERFORMANCE

Approved:

Chairman

Date approved by Chairman: April 10, 1968

ACKNOWLEDGMENTS

I am greatly indebted to many people for help in preparation of this thesis. I thank the members of my reading committee, Professor Cecil G. Johnson, Dr. Joseph W. Wray, and Professor William N. Cox, Jr., for reading the original draft of the thesis for content and form. Professor Johnson, my thesis advisor, gave invaluable assistance and recommendations which have certainly resulted in a more meaningful thesis.

My thanks to Mr. Art Abling, Engineering Experiment Station, Georgia Institute of Technology, for his assistance in the design of the circuit for the handedness board control panel. Mr. Abling also gave his technical advice in the field of numerical control machinery which was very helpful.

I express my sincere appreciation to my parents, Dr. and Mrs. Evan L. Kelley, for their continued confidence in me and for the motivation they provided. The patience and understanding and encouragement from my wife, Janette, contributed greatly to the completion of the thesis. Finally, I thank the students of the Georgia Institute of Technology who served as subjects in my experiments.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF ILLUSTRATIONS

SUMMARY

The nature of handedness and its relation to job performance was investigated. During the investigation thirty-seven white male subjects performed four manual tasks and completed a questionnaire. The subjects performed the tasks in similar environmental conditions. The instructions for the subjects were played with a magnetic tape recorder.

Six primary variables were considered: demonstrated hand preference, relative ability of the two hands (handedness), eyedness, performance rate, job performance differential between the left and right hands, and questionnaire hand preference. Analysis indicated that the job performance differential is significantly dependent on handedness, but the relationship of the job performance differential to potential performance rate was not found. Consequently, it was concluded that the Handedness Board Test provides a reliable estimate of the job performance differential, but it was impossible to draw conclusions pertaining to the value of the measure of handedness in estimating job performance.

CHAPTER I

INTRODUCTION

This study investigated the nature of the range of handedness, i.e., whether people might be classified according to their degree of handedness or whether they are either left-handed, right-handed, or ambidextrous. The relation of handedness to job performance was investigated.

The subject of this thesis came from a case study involving Professor Cecil G. Johnson and a child who was having difficulty in learning to read. Since the youngster had previously demonstrated qualities indicative of above average physical and mental abilities, the parents became concerned. Counsel from experienced teachers brought several comments that this type of behavior pattern was often prevalent among ambidextrous children. Later, this child's behavior patterns were extensively observed and it was concluded that he was perhaps uniquely ambidextrous. Subsequent changes in teaching techniques for this individual child caused the child to progress rapidly to above average performance in reading skill for his age class. This episode led Professor Johnson to ask, "Does handedness have a relation to job performance?"

Mr. Douglas E. Bledsoe, working under Professor Johnson, carried out a preliminary investigation as part of a special problem course at the Georgia Institute of Technology. Mr. Bledsoe's results were inconclusive because of the small sample size and several uncontrolled variables. However, he developed a very useful experimental procedure with his handedness board.

Many questionnaires and simple tests are available which measure hand preferences or learned hand skills. If the questionnaire is extensive and unbiased, the hand preferences measured may be related to handedness. In this investigation a measure of handedness was sought which would be reliable and practical.

The principles of motion economy as developed by Barnes and the Gilbreths (1) prescribe a workplace for manual tasks that provides equal work load distribution between the hands. Barnes and the Gilbreths also advocate opposite and symmetrically directed arm movements. Barnes further states that the motions of the hands should be symmetrical and simultaneous. The basis of the several motion-economy principles is the assumption that operators can perform equally well with either the left or right arm and hand for most manual tasks, yet it is evident that a difference in the work ability of the hands and arms exists. Observation of people using common tools and writing instruments reveals that most people consistently use their right hand to perform operations requiring skills while only 4 percent of the population consistently uses the left hand (2). The significance of the ratio of the number of right-handed individuals to the number of left-handed individuals should be considered in the design of work centers if individual differences in handedness are a factor which significantly affects job performance.

In the first investigation the handedness of each of thirty-seven white male college students between the ages of 19 and 28 was measured with a handedness board. Then their hand preferences were measured by a forced handedness demonstration, a questionnaire, and by direct observation.

If the data from these experiments are significantly correlated, the handedness board could be considered a reliable device with which to measure handedness. The job performance at the task of dealing cards in a prescribed manner was also measured for each subject and the relationship of handedness to job performance was investigated.

CHAPTER II

LITERATURE REVIEW

Plan

The literature search was concentrated on the subject of handedness. Initially, the references of Douglas E. Bledsoe in his preliminary investigation report, "An Investigation of Handedness and its Relation to Job Performance," were searched for information on the subject. Then books, articles, and abstracts that were published in the last ten years and written on topics of handedness, hand preference, dexterity, laterality, lateral dominance, or motor skills were searched for information pertaining to handedness. Finally, the bibliographies of the previous literature were used to find additional sources of information on handedness. Approximately five hundred references were discovered, with a list of thirty-one references of value resulting.

Measurement of Handedness

Despite the large quantity of literature on handedness, comparatively few studies have been concerned with the relative performance of the preferred and nonpreferred hands in groups of right- and left-handed individuals. Unfortunately, typical studies often fail to separate clearly the influence of left-handedness, on the one hand, and ambilaterality (or ambidexterity or mixed motor performance) on the other (3). The potential theoretical significance of a differentiated versus undifferentiated classification of handedness has not usually been considered, and individuals with ambilateral or ambidexterous tendencies have all too often been classified as left-handed. According to Palmer (12), "It is therefore difficult to know if the results of these studies are due to 'leftness' per se, or to a relatively less differentiated handedness." Classification is further complicated by the fact that left-handers tend, on the average, to be more variable in their hand preferences (3), (9), (12), (13), (14). Despite the barriers, many methods, both quantitative and qualitative, have been devised as an attempt to measure handedness.

Several studies have used some type of questionnaire for either preliminary grouping (14) or for statistical classifications (5), (10). Other studies employ the use of measurable variables with hopes that some correlation of value will result. However, since no standard measure or definition of handedness has been established by an acceptable authority a majority of the recorded experiments investigate some selected variable for its value as a handedness indicator. Many such indicators have been investigated. Simon (14) concluded that steadiness cannot be regarded as a sensitive index of handedness, whereas steadiness measured with a standard test was correlated with the handedness of a group previously classified by a handedness questionnaire. One author (7) made a lengthy study in which handedness was a variable. The supposed handedness was measured by a questionnaire consisting of nine questions pertaining to hand preference. Krampen (10) based one of his experiments involving the importance of handedness as a variable in determining "apparent movement" on the assumption that a person is either right- or left-handed, that fact confirmed by observing which hand is used in writing. Gesell and Ames (8) periodically observed a group of subjects with ages ranging up to ten years with special emphasis on the first few years of life. They concluded from their observations that definite hand preferences change as many as fourteen times just in the first eight years of life. They assumed a significant correlation of handedness with the time in contact with a stimulus object and, by means of a film analysis, the nature of the tonic neck reflex. The nature of the results seemed significant. However, the validity of the entire experiment is contingent on the assumed correlation.

Beck (3) stated that "... a left-handed man in this right-handed world is forced to acquire a considerable degree of skill with his right hand." If a test of manual skill is used which is similar to a task in which culture has dictated the use of the right hand, the right-handed and part of the left-handed people should show a superiority of the right hand. Beck proffers that the effect of unequal practice does not impair the discriminative value of the tests because the distribution of intermanual differences merely shifts in the direction of superiority of the right hand. According to Beck, "This fact necessitates the use of an emperical criterion, separating the dextrals and sinistrals on the basis of the distribution curves for the two groups, rather than on an absolute criterion... ."

In the words of Palmer, "... the literature on handedness is susceptible of two major criticisms. The first relates to the too exclusive concern with the pragmatic right versus left distinction... . A second criticism concerns the tendency to rely upon questionnaire 'consistency' measures of handedness, to the exclusion of behavioral measures of the level of an individual's proficiency with each hand." The result of the first restriction has been an over-compartmentalized view of handedness.

The second criticism comes from the question of whether consistent preferences necessarily signify a strong unimanual proficiency (12). Palmer suggests that the proficiency of each hand should be measured separately and in different tasks in order to obtain more complete and reliable information.

The Science of Experimental Investigation of Handedness

The many writers and investigators of handedness present a variety of conflicting conclusions from their experiments as well as many differing recommendations. Of interest here are some of the comments concerning experimental design, construction, execution, and control.

The literature review indicates that the relation between reported handedness and skilled performance is far from perfect, i.e., handedness surveys or questionnaires and relative work ability of the two hands have given very little correlation.

Simon (14) suggests that fine manipulative tasks provide more effective indices of handedness than various positioning tasks. Fahrion (6) has indicated that the time at which experiments are conducted should not vary considerably, especially when dealing with handedness. He concludes that it is likely that relative hand performance would vary with time and activity. Fahrion prefers a morning hour.

Crovitz and Zener (5) proportion the success of testing to the amount of control over the subjects. They suggest that subjects be cautioned to keep their heads erect; to move only with specific instructions; and to refrain from practicing between trials.

In a surprising majority of the experiments and investigations that have been made, the purpose has been to prove some variable to be a true and valid index of handedness. In many experiments apparently very little thought, if any, was given to the validity of the original method of deciding handedness with which the variable was subsequently tested for correlation. Beck (3) contends that one of the most serious criticisms of tests which have been used previously to measure handedness is their simplicity, i.e., their failure to demand the highest degree of precision, accuracy, and speed in performance. In Bledsoe's handedness study (4), a lack of precision in measurement and the use of an inadequate sample size brought results insufficient to allow any definite conclusions to be made. Beck also points out that tests which involve tasks similar to everyday performances are not valid tests of handedness because of the extent to which training affects relative work ability. Provins (13) observed that differences in performance between the preferred and nonpreferred hand vary considerably from one task to another, perhaps because of the previous training on similar yet different tasks or perhaps due to the complexity of the tasks.

Summary of Findings

The literature review suggests a need for a measure, in degree if it exists, of differentiated handedness, a measure of hand preference with at least three categories, and correlation tests of these results with job performance.

Most individuals are aware of their personal hand preferences and therefore this variable should be measurable consistently and accurately by a questionnaire. The measure could be supported by direct observation involving a few simple tasks.

By the definition of handedness, the attempt to measure it must not be subject to a bias caused by a learning effect. The test must measure the relative control or work ability of the two hands, not relative job performance. Therefore, the test should feature control as the only variable to be measured.

Specifically, there are the following recommendations concerning handedness experiments.

1. Questionnaires should be extensive and deal with skilled operations.

2. Handedness tests should be dissimilar to tasks which the subject may have confronted previously.

3. A differentiated degree of handedness should be considered when analyzing experimental data.

4. Each hand should be measured separately to determine the proficiency of the hands.

5. Fine manipulative tasks should be used to determine handedness.

6. The time at which experiments are conducted should not vary considerably.

7. Subjects should be cautioned to move only with specific instructions and to refrain from practicing between trials.

8. The tests should demand a high degree of precision and accuracy of the subject.

9. Several tasks should be included in the experiment so that a significant majority of the results agree.

10. The handedness board should be constructed with a uniform slot

and the counter should have a very short cycle time.

The design of the experiments for this thesis and the method in which they were conducted were guided by these recommendations.

CHAPTER III

INSTRUMENTATION AND EQUIPMENT

Handedness Board Experiment

The major pieces of equipment used in this experiment were a handedness board and a handedness board control panel. Other equipment included a Wollensak magnetic tape recorder for recorded instructions and a Taylor all-glass centigrade thermometer for measuring the temperature in the laboratory.

Handedness Board

The handedness board is made of 60-65-T6 aluminum alloy plate, 36 inches wide, 24 inches high, and 1/4-inch thick. The 1/4-inch plate was chosen so that the board could be mounted without the use of braces for support. The alloy was selected for its machining properties. The dimensions of the slot extremities are $31\frac{1}{2}$ inches horizontally and $15\frac{1}{2}$ inches vertically. The dimensions are within the normal reach limits prescribed by McCormick (11).

The board features a continuous slot, 0.360 ± 0.005 inch wide, in a winding path across the board. The path includes in random order three straight lengths for each of six different directions, each 30 degrees apart. Except for the changes in direction the path is straight. All changes in direction are made with a 1-inch radius measured to the center of the slot. Path lengths are specified for straight portions only. The slot was cut with a Cinimatic numerical control milling machine at K & S

Tool Engraving Company, Incorporated, Atlanta, Georgia. The milling machine control tape was made on the Card-to-Tape machine in the Rich Electronic Computer Center on the Georgia Institute of Technology campus, Atlanta, Georgia. The information on the control tape is a series of 11,245 coordinates which trace the curve of the slot. The program which generates the curve coordinates is written in Algol 60 for the Burroughs B-5500 computer. The program is listed in Appendix A.

The handedness board has dual micro-switches (Figure 2, page 13) attached to each end of the slot to activate the control panel when the cycle begins. The board is mounted on an adjustable easel which permits variation of the inclination and height of the board. The handedness board is pictured in Figure 1, page 13. A specifications drawing is shown in Figure 3, page 14.

The Stylus

The stylus which the subject passes through the slot is approximately 8 inches long and has a 0.250 ± 0.005 inch diameter cylindrical tip approximately 1-inch long. A flexible 0.20 gage wire is attached to the upper end of the stylus to carry the six-volt potential. The stylus is machined to a comfortable shape from $\frac{1}{2}$-inch aluminum bar stock. The stylus is pictured in Figure 4, page 15.

The Control Panel

The control panel is started automatically by the micro-switches on the board when the stylus begins its cycle. The control panel indicates to the experimenter when the subject is ready, signals the subject to begin, automatically activates two Cramer elapsed time indicators, and it stops the counters at the end of the cycle. One of the elapsed time

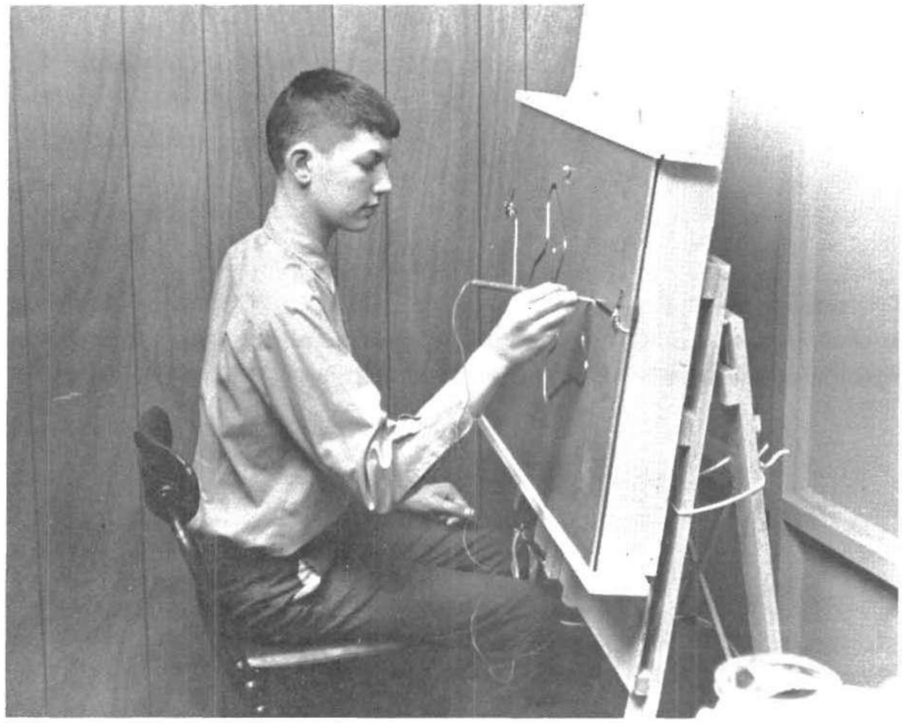

Figure 1. Handedness Board

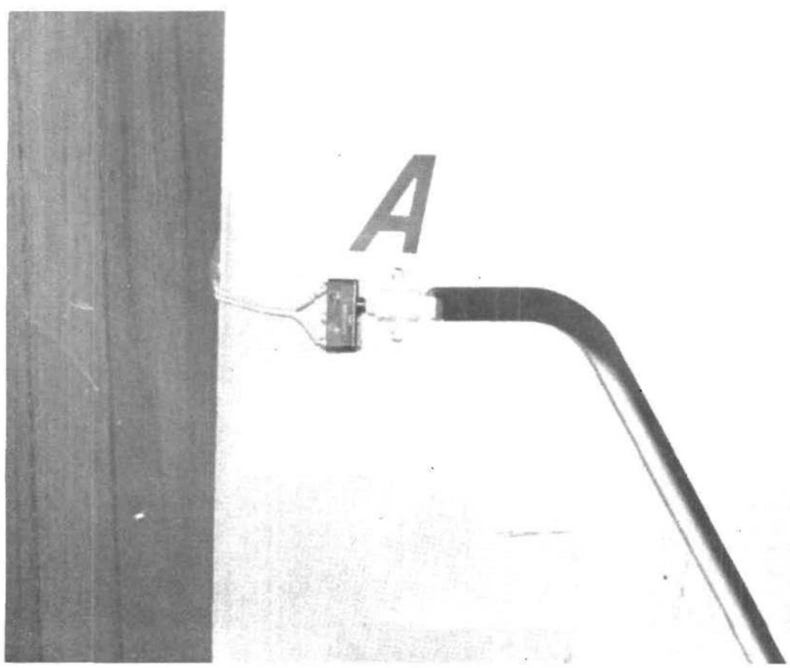

Figure 2. Micro-switches on Handedness Board

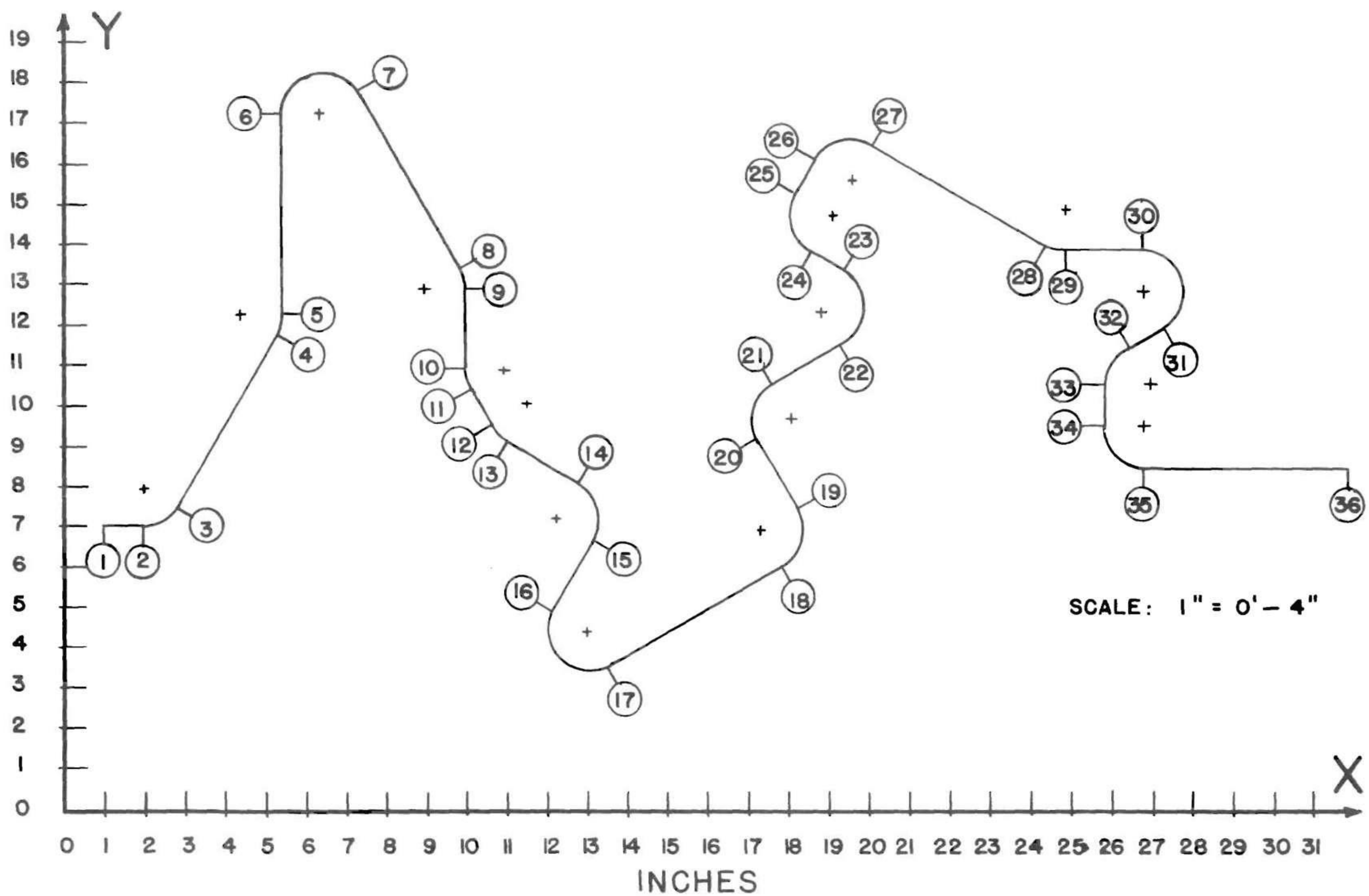

Figure 3. Handedness Board

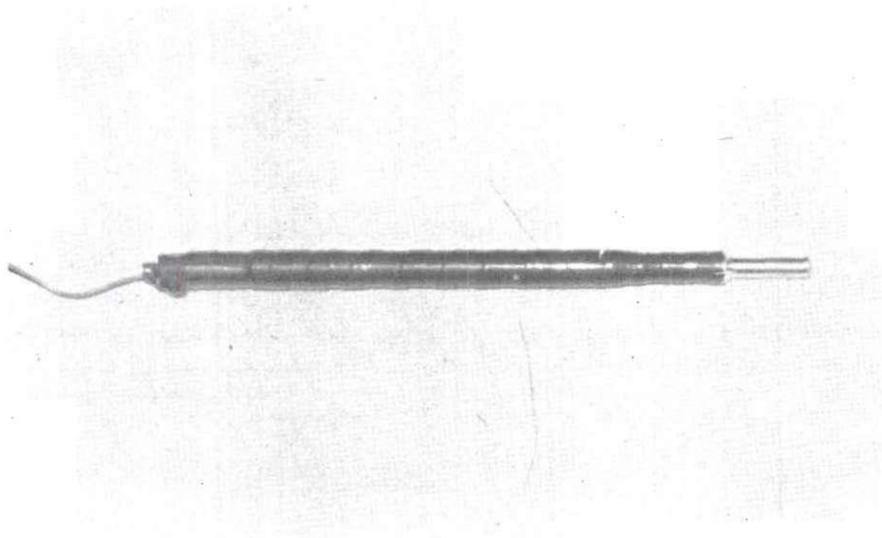

Figure 4. Stylus

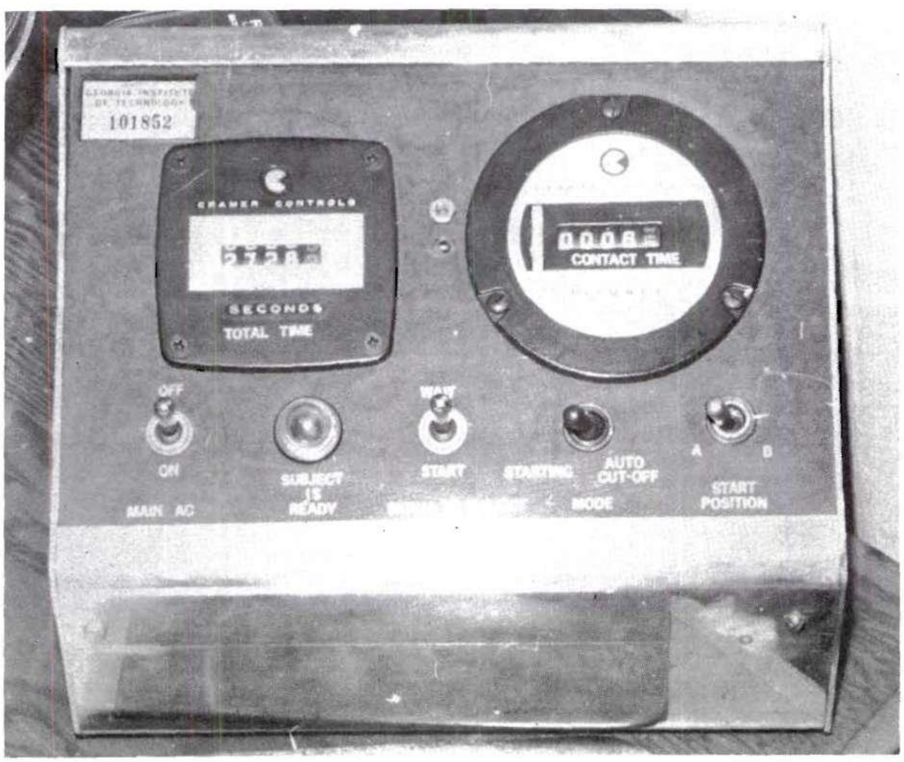

Figure 5. Control Panel

indicators measures the total cycle time while the other records only the time the stylus is in contact with the edge of the slot. The control panel is shown in Figure 5, page 15. The schematic diagram for the complete circuit of the handedness board is shown in Figure 6, page 17, and the parts list is shown in Table 1, page 18.

The following list gives the proper sequence of operations for the control panel switches.

1. Initial settings: MAIN AC - OFF
   SIGNAL TO SUBJECT - WAIT
   MODE - STARTING
   START POSITION - A or B

2. Move the MAIN AC switch to the ON position.

3. When the subject throws the micro-switches with the stylus the SUBJECT IS READY lamp lights.

4. The SIGNAL TO SUBJECT switch is thrown to the START position.

5. After the subject moves the stylus away from the starting position, the MODE switch is thrown to the AUTO CUT-OFF position.

6. When the stylus trips the micro-switches at the starting and stopping position on the board the main AC power line is opened and all counters stop.

7. The MAIN AC switch is returned to the OFF position and then other switches are returned to their initial settings.

Water Manipulation Experiment

The apparatus for this experiment consists of four glass tumblers, a glass pitcher, a layout board and a Wollensak magnetic tape recorder for recorded instructions. All special apparatus for this experiment is de-

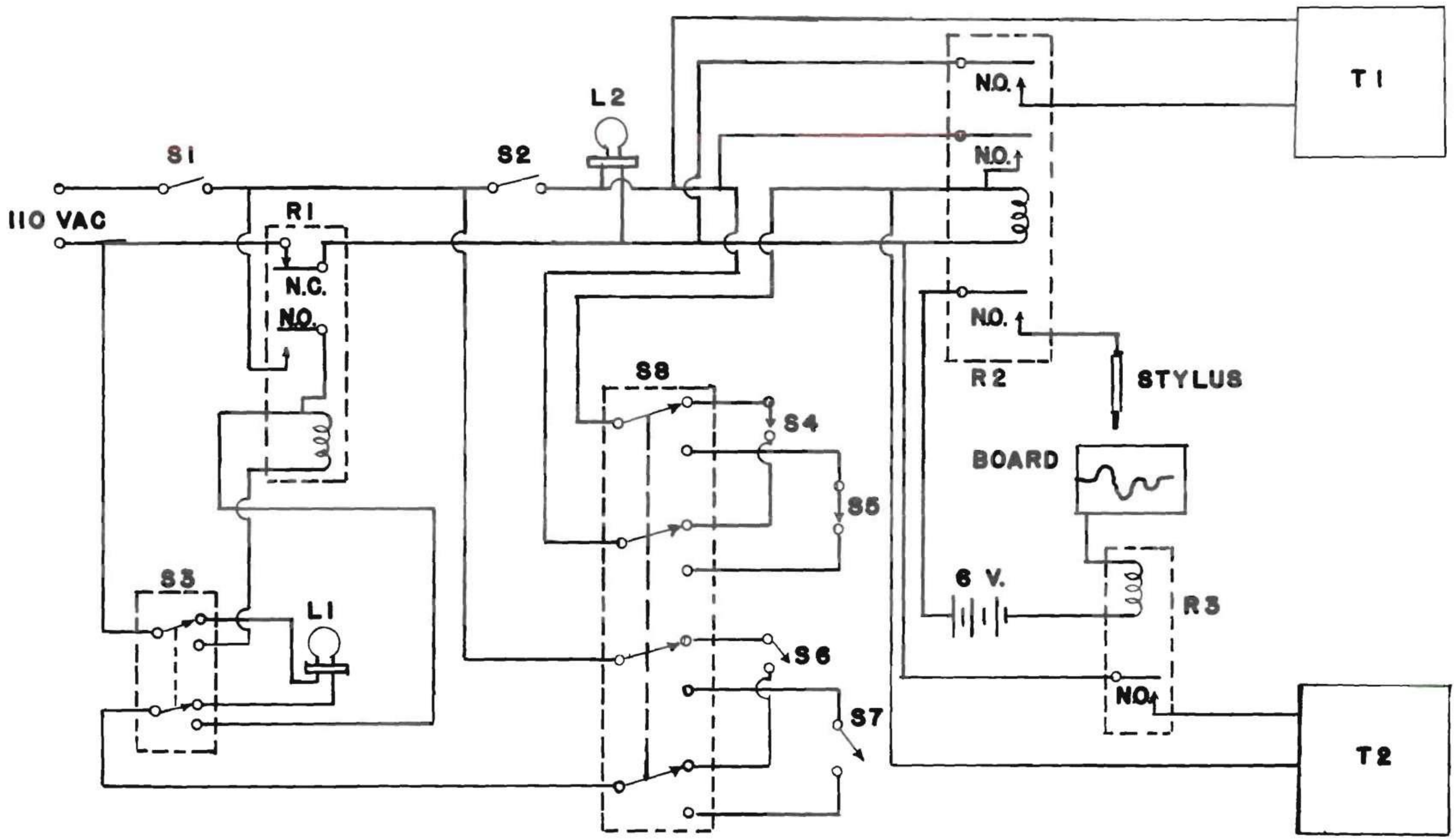

Figure 6. Schematic Diagram for Handedness Board Circuit

Table 1. Handedness Board Experiment Electronics Parts List

Part	Identification	Specifications
S1	MAIN AC switch	Cutler-Hammer SPST Type 8280K16, 6A @ 125v
S2	SIGNAL TO SUBJECT switch	Same as for S1
S3	MODE switch	Cutter-Hammer DPDT Type 7565K5, 15A @ 125v
S4, S5, S6, S7	Micro-switches mounted in pairs at each end of the Handedness Board. S4 and S6 at end A; S5 and S7 at end B	ACRO, SPDT, IMDI-IA, 1/32 inch travel @ 6 oz
S8	START POSITION selector switch	Cutter-Hammer TPDT, Type 7662K7, 15A @ 125v
R1	Relay	Potter and Brumfield, DPDT, 115 VAC coil, Model KA11AY
R2	Relay	Potter and Brumfield, 3PDT, 115 VAC coil, Model KA14AY
R3	Relay	Potter and Brumfield, Dry Reed, SPST, 6v DC coil, Model JR1000
L1	SUBJECT IS READY lamp (mounted on control panel)	General Electric, NE-51, neon glow lamp
L2	START LIGHT (mounted on Handedness Board)	Same as for L1
T1	TOTAL TIME meter	Cramer Model 635S Elapsed Time Indicator, 9999.9 seconds, 115v AC, square bezel, accuracy ± 0.05 sec. per operation, 100% at nominal frequency when running, non-resettable
T2	CONTACT TIME meter	Cramer Model 633E, same as T1 except round bezel and resettable dial
Battery		Ray-O-Vac #941, 6v heavy duty lantern battery

scribed below and is pictured in Figure 7, page 20.

Tumblers

Each tumbler is made of clear glass and will hold 8 ounces. Each tumbler will have a 4-ounce graduation clearly marked by a 1/8-inch wide black band around the glass. The tumblers are the type commonly found in restaurants.

Pitcher

The pitcher is actually a glass quart capacity milk bottle. It is round with a narrow neck and has no markings.

Layout Board

The layout board is made of a sheet of poster paper 20 inches wide and 30 inches long. The board is white with four black disks, 3 inches in diameter, to indicate the position of the tumblers and one black $4\frac{1}{2}$-inch diameter disk to show where the pitcher is to be placed. Each tumbler position is numbered as shown in Figure 7, page 20.

Dot Test

The apparatus for this experiment consists of a 5-inch diameter white target on a black background, a $\frac{1}{4}$-inch diameter by $\frac{1}{2}$-inch long black wooden block mounted at the upper end of a vertical length of brass welding rod, 22 inches long, which is mounted on a 4-inch by 4-inch wooden block 2 inches thick and a Wollensak magnetic tape recorder for taped instructions. The special apparatus for this experiment are shown in Figure 8, page 21.

Card Dealing Experiment

The equipment for this experiment consists of a layout board, two

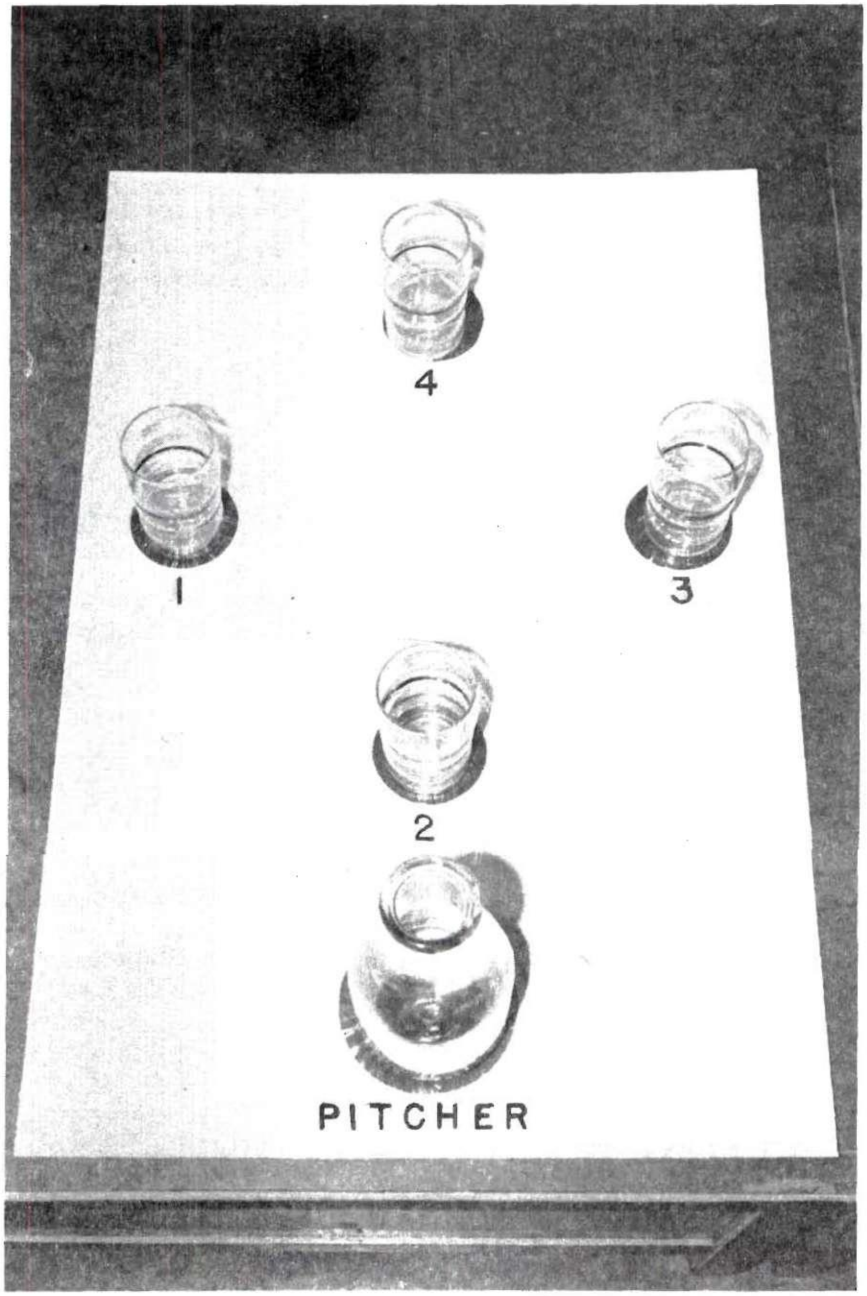

Figure 7. Water Manipulation Apparatus

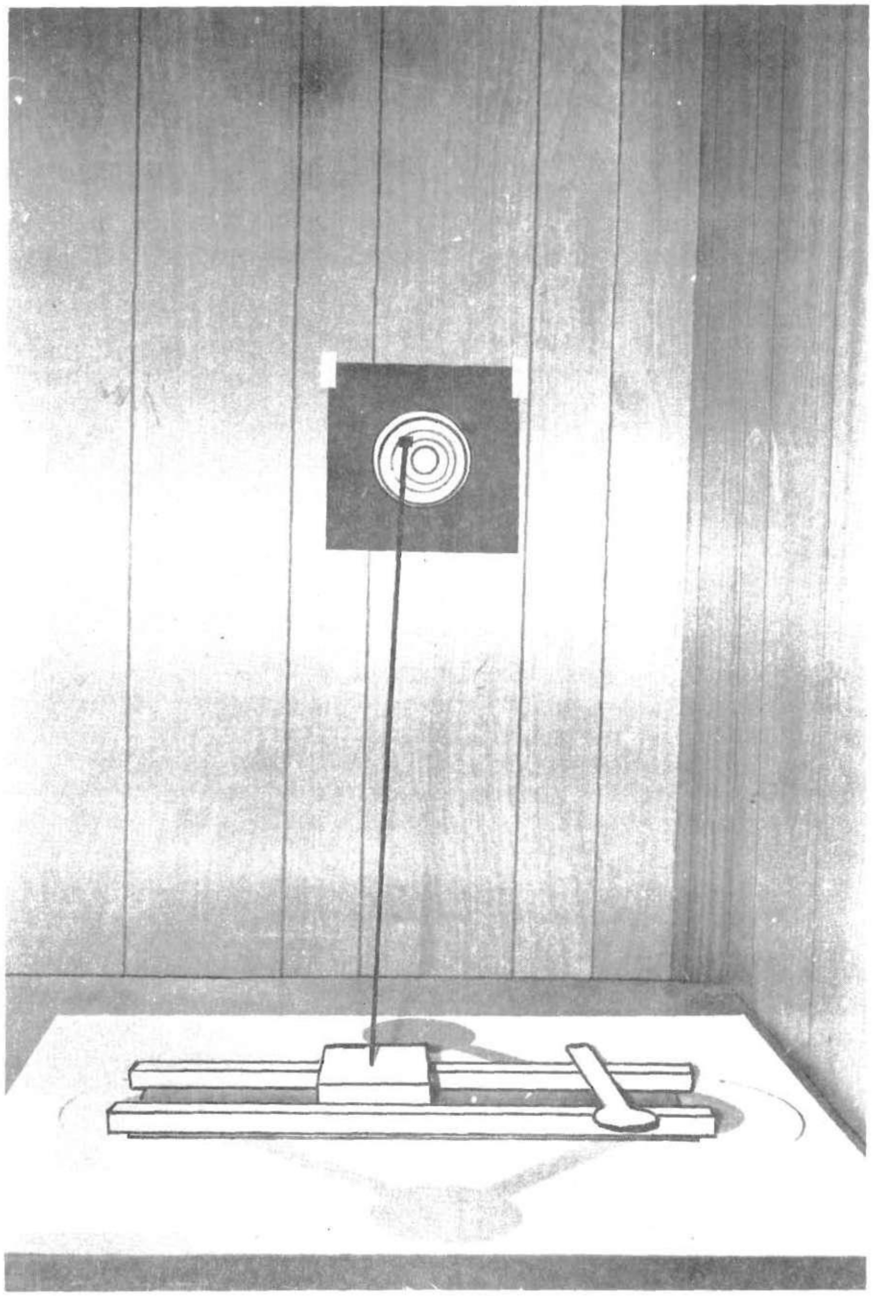

Figure 8. Dot Test Apparatus

decks of cards, a Meylan decimal-minute stop watch, and a Wollensak magnetic tape recorder for playing taped instructions. All apparatus for this experiment are pictured in Figure 9, page 23.

Layout Board

The layout board is made of a white 22-inch by 28-inch sheet of poster paper with orange construction paper disks and lines.

Cards

The cards are "Bee" brand standard playing cards. Club Special No. 92, back number 67 with a cambric finish. Each card measures $2\frac{1}{2}$ inches wide and $3\frac{1}{2}$ inches high.

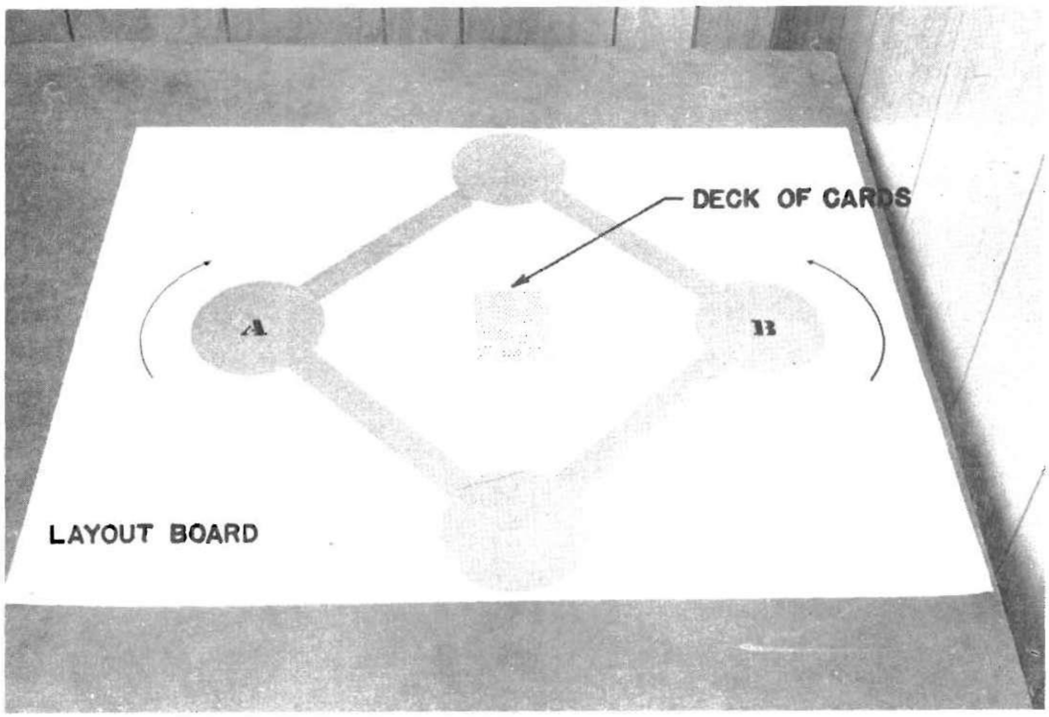

Figure 9. Card Dealing Apparatus

CHAPTER IV

PROCEDURE

Descriptions of the laboratory, the experimental subjects, the experimental designs, the concomitant variables considered, and the procedure followed are presented in this chapter.

Laboratory

A room in the basement of the Industrial Engineering building at the Georgia Institute of Technology, Atlanta, Georgia, was used as the laboratory. The room was lighted with the two diffused lighting fixtures shown in Figure 10, page 25. The level of illumination in the room was seven as measured with a Weston Model IV light meter. The temperature of the room ranged from 24.5 degrees centigrade to 27.5 degrees centigrade during the experiments. There were no heating facilities in the room. The floor was made of concrete and the ceiling of white accoustical tile. Three walls and an included door were covered with maple finish plywood panels. The fourth wall was painted with light green flat finish paint. There were two electrical outlets in the room and a telephone. The specific locations of the camera and various apparatus are shown in Figure 11, page 26.

Subjects

The subjects selected were students at the Georgia Institute of Technology, Atlanta, Georgia. Subjects selected were between the ages of

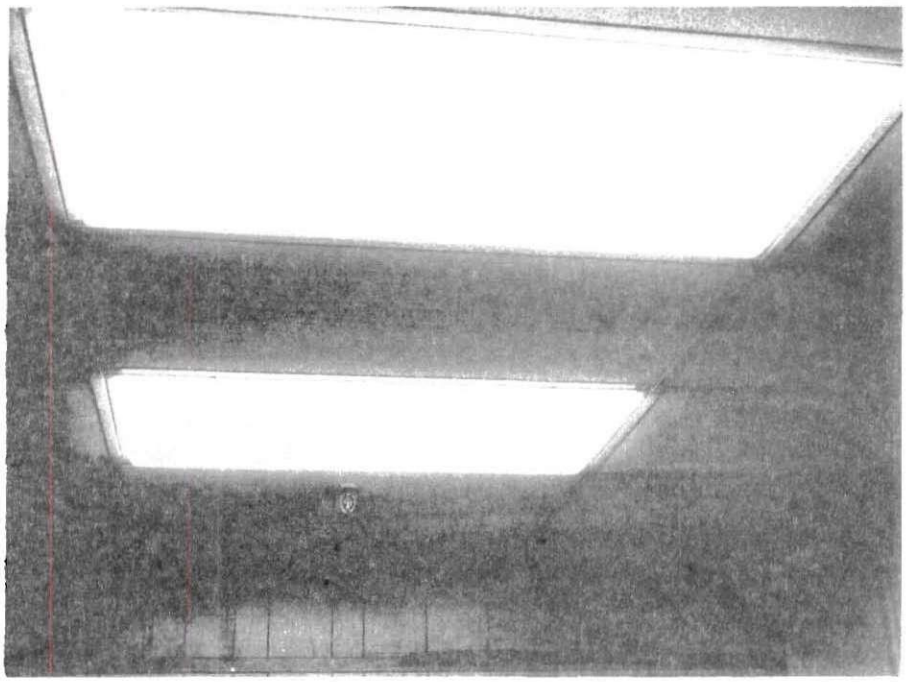

Figure 10. Laboratory Lighting Fixtures

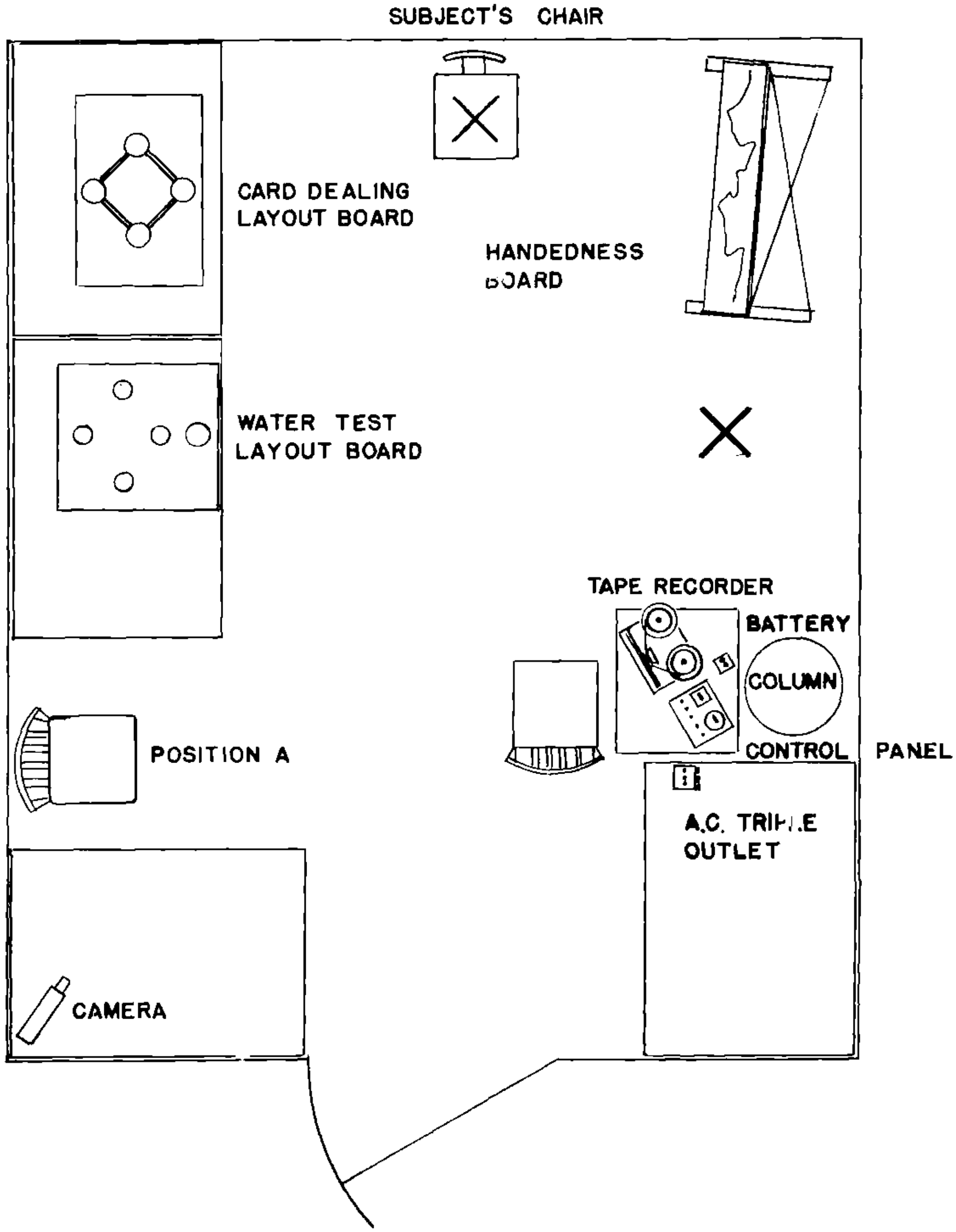

Figure 11. Laboratory Layout

19 and 28 years. This age range was selected so that most of the subjects would have similar work experience which might affect their performances during the experiments. The subjects were interviewed privately immediately prior to the experiments. Only those subjects who possessed normal limbs and eyesight and who indicated neither emotional problems nor activities which might affect the nervous system or the eye-hand coordination were permitted to participiate in the experiments. During the interview the subjects were asked primarily those questions in Figure 15, Page One of the Data Sheet in Appendix C. The subject was not allowed to participate in the experiments if he indicated any prior knowledge of the thesis subject or the purpose of the experiments.

A total of forty-five students were interviewed of whom thirty-seven were selected as subjects.

Concomitant Variables

Although the concomitant variables were generally uncontrollable, several were observed and recorded for possible analysis. The environmental concomitant recorded was room temperature, measured in degrees centigrade. The temperature was recorded at the beginning of the first experiment for each subject. Subject concomitants considered were weight, height, and age. All experiments were run either between the hours of 9:00 A.M. and 11:00 A.M. or 1:00 P.M. and 4:00 P.M. to minimize concomitant variable variance.

The symbols used for the concomitant variables are as follows: X_7 represents the temperature in degrees centigrade of the laboratory at the beginning of the experiments for each subject, X_8 is the subject's age in whole years, and X_9 is the height-weight ratio obtained by dividing the subject's height in inches, by his weight in pounds.

Design of Experiments

Primary Variables

This section gives the symbols and formulas for the primary variables measured during the experiments. The results of the experiments are shown in Figure 15, Page Two in Appendix C.

In the water manipulation experiment the variable RH is the number of times the subject selects his right hand for a task and LH is the number he chooses his left hand. These variables are combined according to the following formula to give a measure of demonstrated hand preference, X_2.

$$X_2 = \frac{RH - LH}{RH + LH}$$

The symbol for the variable measured by the Handedness Board is X_1 and is given by the following formula:

$$X_1 = \frac{s(L) - s(R)}{s(L) + s(R)}$$

s(L) and s(R) are respectively the ratios of contact time to total time for the left and right hands.

X_5, the symbol for eyedness, which is measured by the Dot Test, is given by:

$$X_5 = \frac{(\#R's) - (\#L's)}{(\#R's) + (\#L's)}$$

The #R's and #L's respectively are the number of times the subject places the dot image into the center of the target with his right or left eye.

In the card test the variable X_3 is a measure of the job performance differential which indicates with which hand the subject best performs a task. X_3 is given by the formula:

$$X_3 = \frac{\overline{L} - \overline{R}}{\overline{L} + \overline{R}}$$

where $\overline{L}$ and $\overline{R}$, respectively are the average times to deal a deck of cards with the left and right hands. Another variable derived from the card dealing data is X_4 which gives a performance rating for the dealing time. X_4 is given by:

$$X_4 = \frac{\text{normal time for dealing a deck of cards (0.50 min.)}}{\text{minimum average dealing time (whether left or right hand)}}$$

The data from the questionnaire (see Figure 15, Appendix C) will yield the variable X_6 given by the equation:

$$X_6 = \frac{A - B}{13}$$

where A is the sum of the following values: +1 for each RA circled in questions one through eight and for each LA circled in questions nine through thirteen, $+\frac{1}{2}$ for each RM circled in questions one through eight and for each LM circled in questions nine through thirteen. B, similarly, is the sum of these values: $+\frac{1}{2}$ for each LM circled in questions one through eight and for each RM circled in questions nine through thirteen, and +1 for each LA circled in questions one through eight and for each RA circled in questions nine through thirteen.

Analysis

A total of twenty-three correlation tests were made. Calculations were made on the Burroughs B-5500 computer in the Rich Electronic Computer Center at the Georgia Institute of Technology. A standard Bivariate Correlation and Regression Analysis program was used. The original program was written for the Burroughs B-5000 computer in Algol 60 and may be found in the Burroughs Corporation Technical Manual ORS-020/R, April 15, 1962, revised October 25, 1963. The complete modified program, as used, is shown on pages 60-66 in Appendix B. The output of that program for the twenty-three tests is summarized in Table 7 in Appendix C. A glossary of symbols and variables is also given in Appendix C.

The hypothesis tested in each case was that $r_{ij} = 0$. Since

$$b_{ij} = r_{ij} \frac{s_i}{s_j}$$

the hypothesis that $r_{ij} = 0$ was tested by testing the equivalent hypothesis that $b_{ij} = 0$ using a two-tailed t-test. The statistic

$$t_{b_{ij}} = \frac{b_{ij}}{s_{b_{ij}}}$$

was computed for each of the twenty-three cases. If this exceeds $t_{\alpha/2}$ for $n = N-2$, the hypothesis is rejected and the correlation is considered significant at the α level. If the hypothesis is accepted the conclusion is that there is no significant linear correlation between the two variables.

It is true that if X_i and X_j are completely independent, the r_{ij} will be zero; but if $r_{ij} = 0$ it is still possible that X_i and X_j may be related in some other way. The variables were not tested for possible nonlinear relations.

Procedure

Each subject was conditioned immediately prior to the time when he was to perform the sequence of tasks. When he entered the laboratory he was asked to be seated in position A (see Figure 11, page 26). After the interview was concluded the subject was asked to listen very carefully to the tape recorder. From this point on all instructions were played by a tape recorder to the subject. The taped instructions were designed for continuous use. However, the recorder was equipped with a digital counter and an instant stop mechanism which permitted the experimenter to stop the recorder at any point to answer questions from the subject or even replay a given instruction if required. After each instruction was played the experimenter stopped the tape momentarily to allow the subject to complete the task. This procedure permitted the use of one tape for all individuals regardless of individual differences in performance time. The complete sequence of tasks was filmed in memo-motion (32 f.p.m.) for each subject to reduce the human error in data collection.

When the subject was seated in position A the following taped instructions were played:

> You are about to participate in an experiment by performing a sequence of tasks. The tasks are not difficult and you will not be harmed in any way. Since this is a scientific investigation the instructions are being played from this tape recorder so that everyone who participates in this experiment will receive the same instructions. Due to the nature of this project you will not be informed about the

results of your performance until such time as the results of the entire experiment are made available to the public.

During the experiment you will hear this bell frequently (bell sounds). The bell is your signal to carry out the instructions that have been played. If you have any questions before you begin please ask them now.

At this point the subject was allowed to ask questions. When the questions were answered or if there were no questions the tape began the instructions for Experiment I, which was a forced hand preference demonstration. The text follows:

You will see a large X on the floor in front of the table. At the sound of the bell, walk over and stand on the X facing the table (bell sounds). You are about to perform several tasks. Listen carefully to the instructions and execute them promptly after the bell sounds. You will be told when the tasks are completed.

Walk to the table and stand before the pitcher and tumblers (bell sounds). After you complete each task remember to replace the pitcher or the tumbler you have used in its original position on the table. The tasks are about to begin. Pour water from the pitcher into glass number 3 up to the black line and replace the pitcher (bell sounds). Pour the water from glass number 3 into glass number 1 and replace glass number 3 (bell sounds). Pour water from the pitcher into glass number 4 up to the black line and replace the pitcher (bell sounds). Pour the water from glass number 1 to glass number 2 and replace glass number 1 (bell sounds). Pour water from the pitcher into glass number 1 up to the black line and replace the pitcher (bell sounds). Pour the water from glass number 1 into glass number 3 and replace glass number 1 (bell sounds). Pour water from glass number 3 into glass number 4 and replace glass number 3 (bell sounds). Pour water from glass number 2 into the pitcher and replace glass number 2 (bell sounds). Pour water from glass number 4 into glass number 3 and replace glass number 4 (bell sounds). Pour water from glass number 1 into glass number 4 and replace glass number 1 (bell sounds). Pour water from glass number 3 into glass number 2 and replace glass number 3 (bell sounds). Pour water from glass number 4 into glass number 1 and replace glass number 4 (bell sounds). Pour water from glass number 2 into glass number 4 and replace glass number 2 (bell sounds). Pour water from pitcher into glass number 2 up to the black line and replace the pitcher (bell sounds). Pour water from glass number 1 into the pitcher and replace glass number 4 (bell sounds). Pour water from glass number 1 into the pitcher and replace glass number 1 (bell sounds). Pour water from glass number 2 into glass number 3 and replace glass number 2 (bell sounds). Pour water from glass number 3 into the pitcher and replace glass number 3 (bell sounds). The tasks are completed.

Please wait for further instructions.

After the experimenter had recorded the necessary data the tape was started again. After the subject was seated the tape recorder was stopped and the experimenter adjusted the handedness board so that the subject might perform the task within the normal limits of reach (25). After the board was adjusted the experimenter played instructions designed to condition him. The text of the instructions follows:

> Please walk to and be seated in the chair with the large X on it. You are about to perform another task (tape is stopped momentarily for board adjustment). The metal rod the instructor has handed to you is called a stylus. The wire from the stylus carries only six volts and it is insulated. The wires coming from the board are control wires and they also are completely insulated. In the middle of the metal plate you will see a small white light. This light is your signal to begin the cycle. The object of this task is to move the stylus through the slot in the metal plate and try not to touch the edges of the slot more than is necessary. You should hold the stylus very much as you would a pen or pencil when writing. Try to keep the stylus perpendicular to the board as you move it and move at a normal speed. Feel free to sit on the edge of the chair and you may move your head and body as required so you can see the tip of the stylus as you move it through the slot. During the task keep your idle hand in your lap. At the proper time you will place the stylus in end A or B and momentarily press the tip against the protruding metal strip until the white light comes on. When the stylus reaches the end of the slot you will begin moving it back toward the starting position. Remember, the cycle is not complete until the stylus returns to the original starting position and is pressed against the protruding strip. You will perform this task twice. If you have any questions please ask them now.

When the questions were answered, or if there were none, the experimenter selected at random one of the eight following tape number permutations: 1-3, 1-4, 2-3, 2-4, 3-1, 3-2, 4-1, or 4-2. Each sequence gives one right-handed trial and one left-handed trial and the starting positions are randomized. The texts of the four tapes are listed below.

> 1. R-A. The task is about to begin. When you reach position B do not hesitate. Move the stylus through the slot back to the starting position. With your right hand place the stylus tip in position A (bell sounds). Remember to press firmly against the end of the slot.

When the white light comes on you should begin.

2. R-B. The task is about to begin. When you reach position A do not hesitate. Move the stylus through the slot back to the starting position. With your right hand place the stylus tip in position B (bell sounds). Remember to press firmly against the end of the slot. When the white light comes on you should begin.

3. L-A. The task is about to begin. When you reach position B do not hesitate. Move the stylus through the slot back to the starting position. With your left hand place the stylus tip in position A (bell sounds). Remember to press firmly against the end of the slot. When the white light comes on you should begin.

4. L-B. The task is about to begin. When you reach position A do not hesitate. Move the stylus through the slot back to the starting position. With your left hand place the stylus tip in position B (bell sounds). Remember to press firmly against the end of the slot. When the white light comes on you should begin.

The two meter readings were recorded before the start of the task and after each of the two trials. The control panel for this experiment was located in the laboratory as shown in Figure 11, page 26. After the subject completed the second cycle of the handedness board test and the data were recorded, the tape recorder was begun again. The text of the tape follows:

For the next experiment please turn your chair to the left and pull it up to the table. You will perform several tasks at this table. For the first task grasp the block on the table with both hands. It will slide easily from side to side but must not be lifted. You must remember to keep both eyes open during this task and you may raise or lower your head if necessary but do not tilt it. Now, by sliding the base block from side to side, move the block on top of the rod until it appears to be in the center of the ring on the wall opposite you. When the small block is centered in the ring, say "yes."

At this point the instant stop was applied until the subject answered "yes." The experimenter placed a smooth eyepiece over the subject's left eye and the tape was started again.

Do you still see the block in the center of the circle? Again the tape was stopped. If the subject answered "yes" an R was recorded, and an L if the answer was "no." Then the tape started again.

> Please release the base block and look at the experimenter. Now center the block in the ring. Say "yes" when you see it centered. Do you still see the block in the center of the circle?
>
> Please release the base block and look at the experimenter. Now center the block in the ring. Say "yes" when you see it centered. Do you still see the block in the center of the circle? Please release the block and wait for instructions.

When the subject released the block the experimenter moved it to the left of center 6 inches for one trial, and to the right of center 6 inches for the other trial. When the data were recorded the block assembly was removed. A standard deck of playing cards was placed before the subject and the following instructions were played:

> In this task you will be dealing the cards before you to the four orange areas as fast as you accurately can. As you deal you will push the top card off the deck slightly with your thumb so that you may grasp it with your other hand.
>
> Now pick up the cards and place them face down in your right hand (bell sounds). When the bell sounds again begin dealing with your left hand to direction "B" as fast as you accurately can (bell sounds).

When the subject started the experimenter timed him from the time the first card was dealt until the last card hit the table. After the cards were dealt the experimenter cleared away the loose cards and placed another deck before the subject. When the time for that trial was recorded the tape recorder was started again. The same procedure was followed before and after each of the following sets of instructions:

> Pick up the cards and place them face down in your left hand (bell sounds). When the bell sounds again begin dealing with your right hand to direction "B" as fast as you accurately can (bell sounds).
>
> Pick up the cards and place them face down in your right hand (bell sounds). When the bell sounds again begin dealing with your left hand to direction "A" as fast as you accurately can (bell sounds).

Pick up the cards and place them face down in your left hand (bell sounds). When the bell sounds again begin dealing with your right hand to direction "A" as fast as you accurately can (bell sounds).

When the subject completed these tasks and the data were recorded the experimenter gave the subject a handedness questionnaire with the verbal instructions, "Please read the instructions and fill this out with the pencil before you. When you finish, please place the pencil in the holder." When the subject finished this task the experiments were completed.

CHAPTER V

DISCUSSION OF RESULTS

The results of the statistical analysis are summarized in Table 2, page 38. Other results of the analysis are given in Table 7, Appendix C.

The results indicated that only three of the twenty-three tests made had highly significant correlation coefficients. The concomitant variables recorded had no significant effect on any of the primary variables. The demonstrated hand preferences (Water Manipulation Test) are significantly correlated with the hand preferences indicated in the handedness questionnaire (Figure 17 of Appendix C) at the 0.01 level. Also the Handedness Board scores are significantly correlated with the demonstrated hand preferences at the 0.01 level (Figure 18, Appendix C). These results indicate that a measure of an individual's hand preferences can be estimated from the handedness measured by the Handedness Board. The following formula gives hand preference in terms of handedness:

$$X_2 = (1.4177)\, X_1 + 0.60107$$

The correlation of the performance differential to the Handedness Board score is significant at the 0.03 level. This correlation suggests that at least one variable that is related to job performance is significantly dependent on the score from the Handedness Board Test. The regression analysis yields the following formula for estimating the job performance differential from handedness:

Table 2. T-test on 23 Sets of Correlation Coefficients

Case No.	Independent Variable	Dependent Variable	Coefficient of Correlation	Slope t-value
1	X_1	X_2	0.49639	3.0257**
2	X_1	X_3	0.41255	2.3964*
3	X_1	X_4	0.26255	1.4398
4	X_1	X_5	0.33100	1.8501
5	X_1	X_6	0.17648	0.9487
6	X_1	X_7	0.12694	0.6772
7	X_1	X_8	0.15106	0.8086
8	X_1	X_9	0.11071	0.5894
9	X_2	X_5	0.31747	1.7715
10	X_2	X_6	0.72649	5.5943***
11	X_2	X_7	0.12925	0.6897
12	X_2	X_8	0.29068	1.6075
13	X_2	X_9	0.08226	0.4367
14	X_3	X_4	0.19701	1.0633
15	X_3	X_7	0.21257	1.1511
16	X_3	X_8	0.09022	0.4794
17	X_3	X_9	0.24545	1.3398
18	X_4	X_7	0.28151	1.5524
19	X_4	X_8	0.08503	0.4516
20	X_4	X_9	0.18454	0.9935
21	X_6	X_5	0.22526	1.2234
22	X_6	X_8	0.25774	1.4115
23	X_6	X_9	-0.08690	-0.4615

* Significant at the .03 level

** Significant at the .01 level

*** Significant at the 0.001 level

$$X_3 = (0.36125)\ X_1 + 0.1249$$

This regression line is shown on the scatter diagram in Figure 19, Appendix C.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

The literature review revealed that handedness has been investigated by many experimenters. However, it is concluded that these investigations have not adequately explained the relationship of handedness to the total human system. The relationship of handedness to job performance has not previously been determined.

The present experiments investigated the relative work ability of the two hands (handedness) and its relation to job performance. Analysis of the three handedness variables, Handedness Board score, demonstrated hand preference, and questionnaire hand preference indicated a significant correlation among all three variables. Consequently, it is concluded that the Handedness Board may be a useful instrument to provide a reliable measure of handedness. It should be noted that the Handedness Board scores are in decimal form and in this investigation did not generally fall in the extreme possible scores of -1 or +1. The analysis of the two job performance variables, performance rating and the job performance differential indicated that the two variables are not linearly related. Further analysis of all primary variables revealed that performance rating is not significantly correlated with handedness, but the correlation of the job performance differential with handedness is significant at the 0.03 level. It is, therefore, concluded that the Handedness Board may provide a reliable estimate of the job performance differential. Since the relation of the job performance differential to performance rating has not been found, and nonlinear relationships were not investigated, it is impossible to draw conclusions pertaining to the value of the Handedness Board or the job performance differential in estimating an individual's potential rate of job performance.

The analysis of concomitant variables indicated that neither age, room temperature, nor the height-weight ratio had a significant effect on handedness, hand preference, the job performance differential or performance rate.

It should be noted that in the design of experiments only linear correlation tests were made. Additional and possibly more significant results might be obtained if the data were tested for multivariate correlation and for nonlinear relationships.

It should be noted that the subjects had no knowledge of the subject of this thesis prior to or during his experimentation. It is not known whether or not this fact affected the motivation of the subject. Thus, it is impossible to conclude that a subject's performance rating score is a reliable measure of the intended variable: maximum effort performance rating.

The following recommendations are made to those who may be interested in further investigating handedness or the relationship of handedness to job performance. First, it is recommended that some method of motivation be incorporated in experiments dealing with job performance. Second, it is recommended that the word, handedness, when used in classifying subjects be defined as the relative work ability of the two hands, as measured by the Handedness Board described in Appendix A. Third, it is recommended that the data from experiments investigating handedness or job performance be tested for multivariate correlation or possible curvilinear bivariate relationships. Finally, it is recommended that the individual effects of handedness and workplace layout on potential job performance be carefully investigated.

Other Recommendations

The conclusions and recommendations which can be substantially defended by this thesis are listed under Conclusions and Recommendations in this chapter. The comments given in this section are the opinions of the author which he feels may be helpful to the experimenters who may further this investigation.

It is recommended that the subjects for future experiments be selected from several age ranges so that the training effect on handedness may be investigated. It is recommended that the handedness questionnaire be expended to include approximately twenty-five questions. When handedness demonstrations are used to measure hand preferences it is recommended that several different tasks be required in a randomized order with fewer repretitions than were used in the experiments for this thesis.

The Handedness Board used in this thesis is designed for use with adults. If it used to classify children it is suggested that the Handedness Board be rotated 90 degrees and the subjects instructed to stand while performing.

APPENDIX A

Handedness Board Facts

The construction details for the Handedness Board constructed for this thesis are given in the text on pages 11, and 12. In addition, it should be noted that when the subject moves the stylus through a complete cycle of the Handedness Board path he is forced to move through seventy-two path length-path direction combinations. The straight sections of the path are either 1 inch, 2 inches, or 5 inches long, and the directions (measuring horizontally East as 0 degrees) are either, in degrees, 0, 30, 60, 90, 120, 150, 180, 210, 240, 270, 300, or 330. The seventy-two unique combinations in the randomized order in which they appear in the cycle from position A are listed in Table 3, 45. A partial flow diagram for the program which generates the Handedness Board curve coordinates is shown in Figure 12, page 46. The scale drawing of the slot curve, with reference points, is shown in the text in Figure 3, page 14.

Table 3. Handedness Board Path Length-Path Direction Combinations in a Complete Cycle

Length-Direction		Length-Direction	
(inches)	(degrees)	(inches)	(degrees)
1	180	5	0
5	120	5	90
5	90	1	150
5	240	2	0
2	270	5	30
1	240	1	300
2	210	1	210
2	300	2	330
5	150	2	240
2	60	5	330
2	150	2	120
1	30	2	30
1	120	1	60
5	210	2	90
2	180	5	60
1	330	5	270
1	270	5	300
5	180	1	0

```
DL = 0.005 (inches)
DTHETA = 0.005 (radians)
r = 1000
pi = 3.1415926535
X = 01000
Y = 07000
WRITE(X,Y) -------- STARTING POINT
X = 02000
WRITE(X,Y) -------- POINT TWO
K = Y + 01000
H = X
THETA = (3/2)pi

Is THETA > (11/6)pi -- yes --
            no
   X = H + r(cos THETA)
   Y = K + r(sin THETA)
   WRITE(X,Y)
   THETA = THETA + DTHETA
                 -------- POINT THREE
DX = 00025
DY = 000433
L = 5
I = 0

Is I > (L/DL) -- yes --
            no
   X = X + DX
   Y = Y + DY
   WRITE(Y,X)
   I = I + ±
                 -------- POINT FOUR
K = Y + 00500
H = X - 00866
THETA = (11/6)pi

Is THETA > 2pi -- yes --
            no
   X = H + r(cos THETA)
   Y = K + r(sin THETA)
   WRITE(Y,X)
   THETA = THETA + DTHETA
                 -------- POINT FIVE
Y = Y + 05000
WRITE(Y,X) -------- POINT SIX
```

Figure 12. Partial Flow Diagram for Handedness Board Slot Path Program

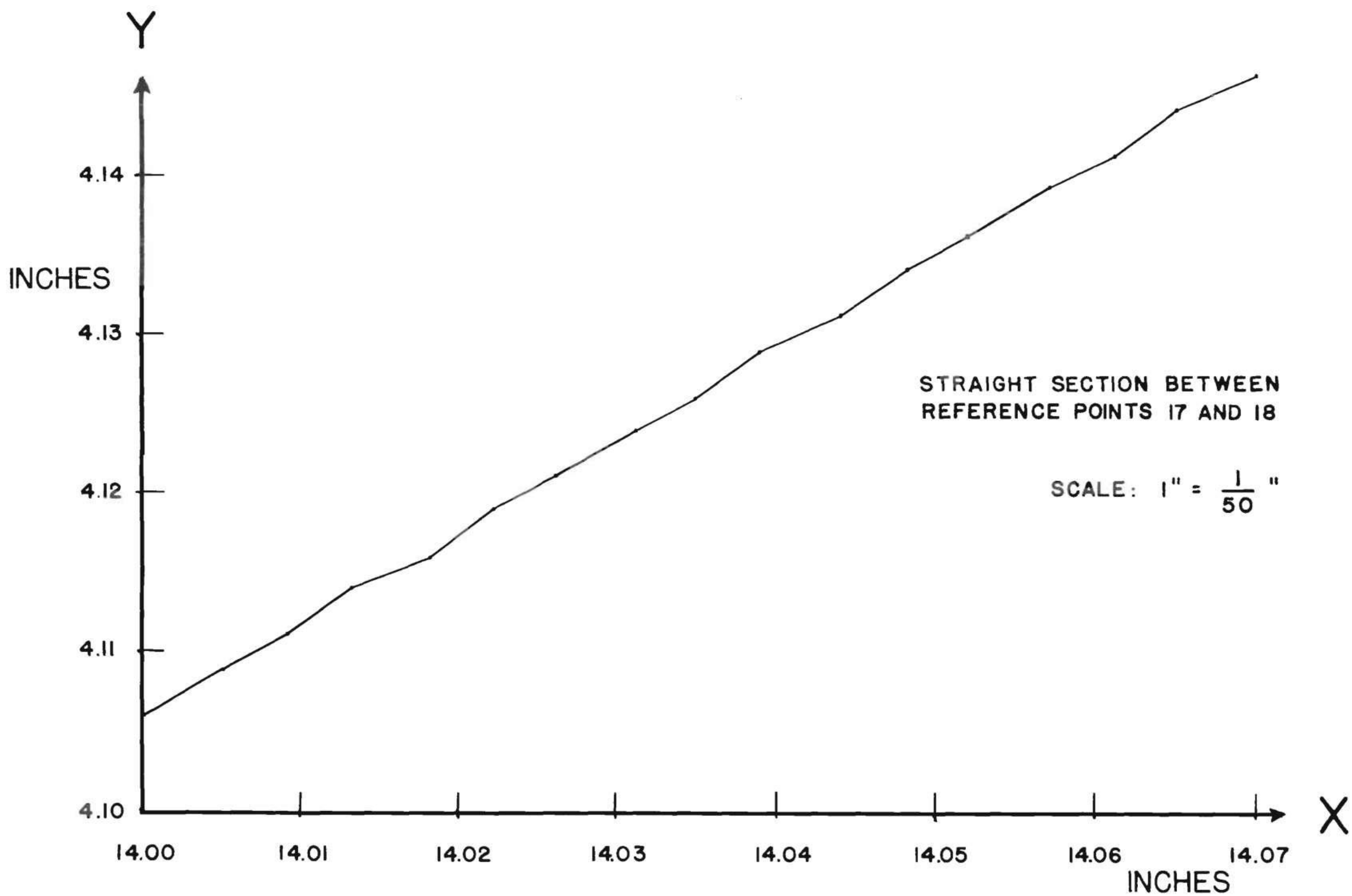

Figure 13. Straight Section of Handedness Board Slot

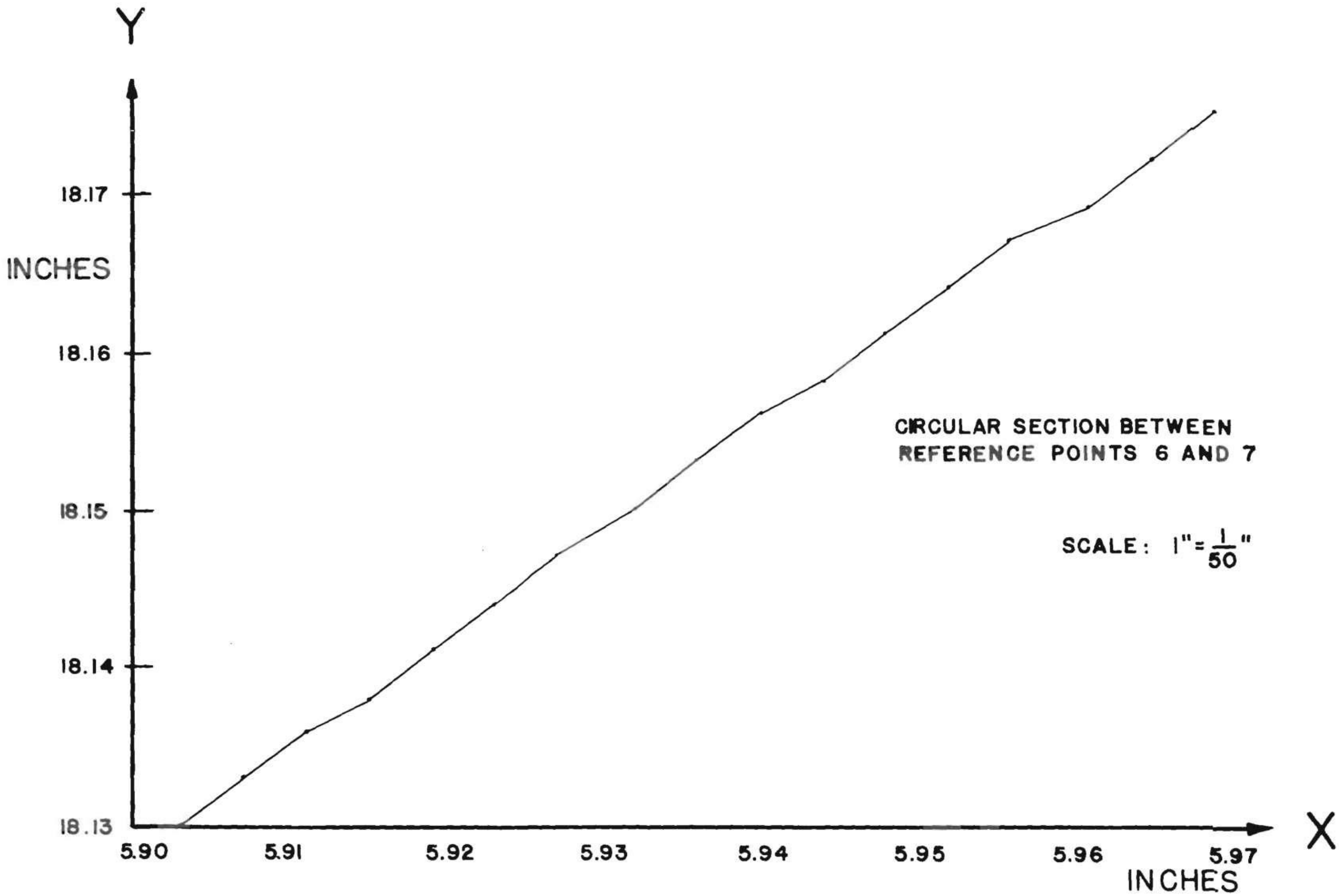

Figure 14. Circular Section of Handedness Board Slot

Table 4. Program Generating Curve Point
Coordinates For Handedness Board Slot Path

```
BEGIN     REAL S, Y, NDT, DT, PI, T, DX, DY ;                           1    0000
                                                          START OF SEGMENT **** 2
          INTEGER I,R,H,K,L,DL,A,AA,N,M, ;                                   0000
          ARRAY XX, YY(0:20,0:1000) ;                                        0000
          LABEL L1,L2,L3    ;                                           3    0002
          FILE IN PDKIN (2,10)                                      ;        0002
          FILE OUT PDKOUT 6(2,15)                                   ;   5    0005
          FILE OUT PDKPUN 0(2,15) ;                                          0009
          LIST ANX(X,Y)                                             ;   6    0012
          LIST ANSR(Y,X)                                            ;   7    0020
          FORMAT FMT1(6("  x",F6.3,"  Y",F6.3)),                             0027
                                                          START OF SEGMENT **** 3
              FMT2(6(".",15,"$",15)) ,                                       0027
               FMT3("TOTAL NUMBER OF COORDINATES =",17) ;                    0027
                                                          3 IS   27 LONG, NEXT SEG 2
          WRITE(POKOUT(NO))                                         ;  15    0027
          DX=2.5 ;  DY = 4.33  ;  PI = 3.1415926535                 ;  16    0029
          NDT = -0.005 ;  DL = 5  ; DT = 0.005 ;  R = 1000          ;  17    0032
          COMMENT START                                             ;  20    0035
          X = 1000  ;  Y = 7000                                     ;  21    0035
          A = 1  ;                                                           0036
          N = A DIV 1000 ;  M = MOD 1000   ;                                 0038
          XX(N,M) = X ;  YY(N,M) = Y  ;                                      0040
          COMMENT POINT ONE                                         ;  23    0044
          X = X + 1000                                              ;  24    0044
          A = A + 1  ;                                                       0045
          N = A DIV 1000 ;   M = A MOD 1000   ;                              0047
          XX(N,M) = A   ;   YY(N,M) = Y  ;                                   0049
          COMMENT POINT TWO                                         ;  26    0053
```

Table 4. (continued)

```
        H = X  ;   K = Y + 1000                                    ;      27    0053
        FOR T = ((3 x PI )/2) STEP DT UNTIL ((11/6 x PI)  DO              28    0054
BEGIN   X = H + (R x COS(T)) ;  Y = K + (R x SIN(T))               ;  C   29    0062
        A = A + 1  ;                                                         0066
        N = A DIV 1000 ;   M = A MOD 1000  ;                                 0068
        XX(N,M) = X ;   YY(N,M) = Y  ;                                       0070
END ;                                                                   31    0074
        COMMENT POINT THREE                                        ;      32    0081
        L = 5000                                                   ;     033    0081
        FOR I = 0 STEP 1 UNTIL (L/DL) DO                              B 054    0081
BEGIN   X = X + DX  ;   Y = Y + DY  ;                                    034    0086
        A = A + 1  ;                                                         0088
        N = A  DIV 1000 ;  M = A MOD 1000  ;                                 0090
        XX(N,M) = X  ;   YY(N,M) = Y  ;                                      0092
END ;                                                                  036    0096
        COMMENT POINT FOUR                                         ;     037    0098
        K = Y + 500 ;  H = X - 866                                 ;     038    0098
        FOR T = ((11/6)xPI)  STEP DT UNTIL (2xPI) DO                     039    0099
BEGIN   X = H + (R x COS(T))  ;   Y = K + (R x SIN(T)              ;     040    0107
        A = A + 1  ;                                                         0110
        N = A DIV 1000 ;   M = A MOD 1000  ;                                 0112
        XX(N,M) = X  ;   YY(N,M) = Y  ;                                      0115
END ;                                                                  042    0119
        COMMENT POINT FIVE                                         ;     043    0119
        Y=Y + 5000                                                 ;     044    0119
        A = A + 1  ;                                                         0120
        N = A DIV 1000 ;   M = A MOD 1000  ;                                 0122
        XX(N,M) = X  ;   YY(N,M) = Y  ;                                      0124
        COMMENT POINT SIX                                          ;     046    0128
        H=Y + 1000  ;   K=Y                                        ;     047    0128
        FOR T = PI STEP NDT UNTI. (PI/6) DO                               48    0130
BEGIN   X = H + (R x COS(T)  ;   Y = K + (R x SIN(T))              ;  C 049    0136
        A = A + 1  ;                                                         0140
```

Table 4. (continued)

```
            N = A DIV 1000 ;   M = A MOD 1000  ;                                  0142
            XX(N,M) = X  ;   YY(N,M) = Y  ;                                       0144
END ;                                                                      051    0148
            COMMENT POINT SEVEN                                       ;    052    0150
            L = 5000                                                  ;    053    0150
            FOR I = 0 STEP 1 UNTIL (L/DL) DO                             B 054    0150
BEGIN       X = X + DX  :   Y = Y - DY                                ;    055    0155
            A= A + 1  ;                                                           0156
            N = A DIV 1000  ;   M = A MOD 1000  ;                                 0159
            XX(N,M) = X  ;   YY(N,M) = Y  ;                                       0161
END ;                                                                      057    0165
            COMMENT POINT EIGHT                                       ;    058    0167
            K = Y -500  ;   H = X - 866                               ;    059    0167
            FOR T = (PI/6) STEP NDT UNTIL 0 DO                             060    0168
BEGIN       X = H + (R x COS(T))  ;   Y = K + (R x SIN(T))            ;  C 061    0175
            A = A + 1  ;                                                          0178
            N = A DIV 1000 ;   M = A MOD 1000  ;                                  0180
            XX(N,M) = X  ;   YY(N,M) = Y  ;                                       0183
END ;                                                                      063    0187
            COMMENT POINT NINE                                        ;    064    0187
            Y - Y - 2000                                              ;    065    0187
            A = A + 1  ;                                                          0188
            N = A DIV 1000 ;   M = A MOD 1000  ;                                  0190
            XX(N,M) = X  ;   YY(N,M) = Y  ;                                       0192
            COMMENT POINT TEN                                         ;    067    0196
            K = Y  ;   H = X + 1000                                   ;    068    0196
            FOR T = PI STEP DT UNTIL ((7/6) x PI) DO                       069    0198
BEGIN       X = H + (R x COS(T))  ;   Y = K + (R x SIN(T))            ;  C 070    0204
            A = A + 1  ;                                                          0208
            N = A DIV 1000 ;   M = A MOD 1000  ;                                  0210
            XX(N,M) = X ;   YY(N,M) = Y ;                                         0213
END ;                                                                      072    0217
            COMMENT POINT ELEVEN                                      ;    073    0219
            L = 1000                                                  ;    074    0219
```

Table 4. (continued)

```
        FOR I = 0 STEP 1 UNTIL (L/DL) DO                              B 075   0219
BEGIN   X = X + DX  ;   Y = Y - DY                                 ;    076   0224
        A = A + 1  ;                                                          0225
        N = A DIV 1000 ;   M = A MOD 1000 ;                                   0228
        XX(N,M) = X ;   YY(N,M) = Y  ;                                        0230
END ;                                                                   078   0234
        COMMENT POINT TWELVE                                       ;    079   0235
        H = X + 866 ;   K = Y + 500                                ;    080   0235
        FOR T = ((7/6) x PI) STEP DT UNTIL ((4/3) x PI) DP              081   0236
BEGIN   X = H +(R x COS(T))  ;   Y = K + (R x SIN(T))              ;  C 082   0244
        A = A + 1  ;                                                          0248
        N = A DIV 1000 ;   M = A MOD 1000  ;                                  0250
        XX(N,M) = X  ;   YY(N,M) = Y  ;                                       0252
END ;                                                                   084   0256
        COMMENT POINT THIRTEEN                                     ;    085   0257
        L = 2000                                                   ;    086   0257
        FOR I = 0 STEP 1 UNTIL (L/DL) DO                              B 087   0257
BEGIN   X = X + DY  ;   Y = Y - DX                                 ;    088   0262
        A = A + 1  ;                                                          0264
        N = A DIV 1000;   M = MOD 1000  ;                                     0266
        XX(N,M) = X  ;   YY(N,M) = Y  ;                                       0268
END ;                                                                   090   0272
        COMMENT POINT 14                                           ;    091   0275
        H = X - 500  ;   K = Y - 866                               ;    092   0275
        FOR T = (PI/3) STEP NDT UNTIL (-PI/6) DO                        093   0276
BEGIN   X = H + (R x COS(T))  ;   Y = K + (R x SIN(T))             ;  C 094   0283
        A = A + 1  ;                                                          0287
        N = A DIV 1000  ;   M = A MOD 1000  ;                                 0289
        XX(N,M) = X  ;   YY(N,M) = Y  ;                                       0292
END ;                                                                   096   0296
        COMMENT POINT 15                                           ;    097   0296
        L = 2000                                                   ;    098   0296
        FOR I = 0 STEP 1 UNTIL (L/DL) DO                              B 099   0296
BEGIN   X = X - DX  ;   Y = Y - DY                                 ;    100   0301
```

Table 4. (continued)

```
          A = A + 1  ;                                                  0303
          N = A DIV 1000  ;  M = A MOD 1000  ;                          0305
          XX(N,M) = X  ;  YY(N,M) = Y  ;                                0308
END ;                                                            102    0312
          COMMENT POINT 16                                   ;   103    0314
          H = X + 866  ;  K = Y - 500                        ;   104    0314
          FOR T = ((5/6) x PI) STEP DT UNTIL ((5/3) x PI) DO     105    0315
BEGIN     X = H + (R x COS(T))  ;  Y = K +(R x SIN(T))       ; C 106    0323
          A = A + 1  ;                                                  0327
          N = A DIV 1000  ;  M = A MOD 1000  ;                          0329
          XX(N,M) = X  ;  YY(N,M) = Y  ;                                0331
END ;                                                            108    0335
          COMMENT POINT 17                                   ;   109    0336
          L = 5000                                           ;   110    0336
          FOR I = 0 STEP 1 UNTIL (L/DL) DO                     B 111    0336
BEGIN     X = X + DY  ;  Y = Y + DX                              112    0341
          A = A + 1  ;                                                  0343
          N = A DIV 1000  ;  M = A MOD 1000  ;                          0345
          XX(N,M) = X  ;  YY(N,M) = Y  ;                                0347
END ;                                                            114    0351
          COMMENT POINT 18                                   ;   115    0354
          H = X - 500  ;  K = Y + 866                        ;   116    0354
          FOR T = ((5/3) x PI) STEP DT UNTIL ((13/6) x PI) DO    117    0355
BEGIN     X = H + (R x COS(T))  ;  Y = K + (R x SIN(T))      ; C 118    0363
          A = A + 1  ;                                                  0367
          N = A DIV 1000  ;  M = A MOD 1000  ;                          0369
          XX(N,M) = X  ;  YY(N,M) = Y  ;                                0371
END ;                                                            120    0375
          COMMENT POINT 19                                   ;   121    0376
          L = 2000                                           ;   122    0376
          FOR I = 0 STEP 1 UNTIL (L/DL) DO                     B 123    0376
BEGIN     X = X - DX  ;  Y = Y + DY                          ;   124    0381
          A = A + 1  ;                                                  0383
          N = A DIV 1000  ;  M = A MOD 1000  ;                          0385
          XX(N,M) = X  ;  YY(N,M) = Y  ;                                0387
END ;                                                            126    0391
          COMMENT POINT 20                                   ;   127    0394
```

Table 4. (continued)

```
          H = X + 866  ;   K = Y + 500                         ;       128   0394
          FOR T = ((7/6) x PI) STEP NDT UNTIL ((2/3) x PI) DO          129   0395
BEGIN     X = H + (R x COS(T))  ;   Y = K + (R x SIN(T)        ;     C 130   0403
          A = A + 1  ;                                                       0407
          N = A DIV 1000  ;   M = A MOD 1000  ;                              0409
          XX(N,M) = X  ;   YY(N,M) = Y  ;                                    0411
END ;                                                                  132   0415
          COMMENT POINT 21                                     ;       133   0416
          L = 2000                                             ;       134   0416
          FOR I = 0 STEP 1 UNTIL (L/DL) DO                           B 135   0416
BEGIN     X = X + DY  ;   Y = Y + DX                           ;       136   0421
          A = A + 1  ;                                                       0423
          N = A DIV 1000  ;  M = A MOD 1000  ;                               0425
          XX(N,M) = X  ;   YY(N,M) = Y  ;                                    0427
END ;                                                                  138   0431
          COMMENT POINT 22                                     ;       139   0434
          H = X - 500  ;   K = Y + 866                         ;       140   0434
          FOR T = ((5/3) x PI) STEP DT UNTIL ((7/3) x PI) DO           141   0435
BEGIN     X = H + (R x COS(T))  ;   Y = K + (R x SIN(T))       ;     C 142   0443
          A = A + 1  ;                                                       0447
          N = A DIV 1000  ;   M = A MOD 1000  ;                              0449
          XX(N,M) = X  ;   YY(N,M) = Y  ;                                    0451
END ;                                                                  144   0455
          COMMENT POINT 23                                     ;       145   0456
          L = 1000                                             ;       146   0456
          FOR I = 0 STEP 1 UNTIL (L/DL) DO                           B 147   0456
BEGIN     X = X - DT  ;   Y = Y + DX                           ;       148   0461
          A = A + 1  ;                                                       0463
          N = A DIV 1000  ;   M = A MOD 1000  ;                              0465
          XX(N,M) = X  ;   YY(N,M) = Y  ;                                    0467
END ;                                                                  150   0471
          COMMENT POINT 24                                     ;       151   0472
          H = X + 500  ;   K = Y + 866                         ;       152   0472
```

Table 4. (continued)

```
          FOR T = ((4/3)xPI) STEP NDT UNTIL ((5/6)xPI) DO                  153   0474
BEGIN     X = H + (R x COS(T))  ;   Y = K (R x SIN(T))              ;   C 154   0481
          A = A + 1  ;                                                          0485
          N = A DIV 1000  ;   M = A MOD 1000  ;                                 0487
          XX(N,M) = X  ;   YY(N,M) = Y  ;                                       0490
END ;                                                                     156   0494
          COMMENT POINT 25                                          ;     157   0494
          L = 1000                                                  ;     158   0494
          FOR I = 0 STEP 1 UNTIL (L/DL) DO                              B 159   0494
BEGIN     X = X + DX  ;   Y = Y + DY                                ;     160   0499
          A = A + 1  ;                                                          0501
          N = A DIV 1000  ;   M = A MOD 1000  ;                                 0503
          XX(N,M) = X  ;   YY(N,M) = Y  ;                                       0506
END ;                                                                     162   0510
          COMMENT POINT 26                                          ;     163   0510
          H = X + 866  ;   K = Y - 500                              ;     164   0510
          FOR T =      ((5/6xPI) STEP NDT UNTIL (PI/3)  DO                165   0512
BEGIN     X = H + (Rx COS(T))  ;   Y = K + (R x SIN(T))             ;   C 166   0519
          A = A + 1  ;                                                          0523
          N = A DIV 1000  ;   M = A MOD 1000  ;                                 0525
          XX(N,M) = X  ;   YY(N,M) = Y  ;                                       0527
END ;                                                                     168   0531
          COMMENT POINT 27                                          ;     169   0532
          L = 5000                                                  ;     170   0532
          FOR I = 0 STEP 1 UNTIL (L/DL) DO                              B 171   0532
BEGIN     X = X + DY  ;   Y = Y - DX  ;                                         0537
          A = A + 1  ;                                                          0540
          N = A DIV 1000  ;   M = A MOD 1000  ;                                 0541
          XX(N,M) = X  ;   YY(N,M) = Y  ;                                       0543
END ;                                                                     174   0547
          COMMENT POINT 28                                          ;     175   0550
          H = X + 500;   K = Y + 866                                ;     176   0550
          FOR T = ((4/3)xPI) STEP DT UNTIL ((3/2)xPI) DO                  177   0551
```

```
BEGIN   X = H + (R X COS(T))  ;   Y = K + (R x SIN(T))          ;  C 178  0559
        A = A + 1  ;                                                   0563
        N = A DIV 1000  ;   M = A MOD 1000  ;                          0565
        XX(N,M) = X  ;   YY(N,M) = Y  ;                                0567
END ;                                                             180  0571
        COMMENT POINT 29  ;                                            0572
        X=X + 2000                                              ;  182  0572
        A = A + 1  ;                                                   0572
        N = A DIV 1000  ;   M = A MOD 1000  ;                          0574
        XX(N,M) = X  ;   YY(N,M) = Y  ;                                0577
        COMMENT POINT 30                                        ;  184  0581
        H = X  ;   K = Y - 1000                                 ;  185  0581
        FOR T = (PI/2) STEP NDT UNTIL (-PI/3) DO                   186  0582
BEGIN   X = H + (R x COS(T))  ;   Y = K + (R x SIN(T))          ;  C 187  0589
        A = A = 1  ;                                                   0593
        N = A DIV 1000  ;   M = A MOD 1000  ;                          0595
        XX(N,M) = X  ;   YY(N,M) = Y  ;                                0597
END ;                                                             189  0601
        COMMENT POINT 31                                        ;  190  0604
        L = 1000                                                ;  191  0604
        FOR I = 0 STEP 1 UNTIL (L/DL) DO                         B 192  0604
BEGIN   X = X - DY ;   Y = Y - DX                                  193  0609
        A = A = 1  ;                                                   0610
        N = A DIV 1000  ;   M = A MOD 1000  ;                          0613
        XX(N,M) = X  ; YY(N,M) = Y  ;                                  0615
END ;                                                             195  0619
        COMMENT POINT 32                                        ;  196  0620
        H = X + 500  ;   K = Y - 866                            ;  197  0620
        FOR T = ((2/3)xPI) STEP DT UNTIL PI DO                     198  0621
BEGIN   X = H + (R x COS(T))  ;   Y = K + (R x SIN(T))          :  C 199  0628
        A = A + 1  ;                                                   0632
        N = A DIV 1000  ;   M = A MOD 1000  ;                          0634
        XX(N,M) = X  ;   YY(N,M) = Y  ;                                0636
END ;                                                             201  0640
        COMMENT POINT 33                                        ;  202  0641
        Y = Y - 1000                                            ;  203  0641
        A = A + 1  ;                                                   0641
```

Table 4. (continued)

```
            N = A DIV 1000  ;   M = A MOD 1000  ;                                   0643
            XX(N,M) = X  ;   YY(N,M) = Y  ;                                         0646
            COMMENT POINT 34                                        ;    205        0650
            H = X + 1000  ;   K = Y                                 ;    206        0650
            FOR T = PI STEP DT UNTIL ((3/2)xPI) DO                           207    0651
BEGIN       X = H +(R  x COS(T))  ;   Y = K + (R x SIN(T)           ;  C 308        0658
            A = A + 1  ;                                                            0662
            N = A DIV 1000  ;   M = A MOD 1000  ;                                   0664
            XX(N,M) = X  :   YY(N,M) = Y  ;                                         0666
END ;                                                                    210        0670
            COMMENT POINT 35                                        ;    211        0671
            X = X + 5000                                            ;    212        0671
            A = A + 1  ;                                                            0671
            N = A DIV 1000  ;   M = A MOD 1000  ;                                   0673
            XX(N,M) = X  ;   YY(N,M) = Y  ;                                         0676
            COMMENT POINT 36                                        ;    214        0680
            COMMENT  LAST X-VALUE CRITICAL IF _ 48000               ;    215        0680
            AA = A ;                                                                0680
            WRITE(PDKOUT, FMT1, FOR A = 1 STEP 1 UNTIL AA DO (XX(A DIV 1000,        0680
               A MOD 1000) x @-3, YY(A DIV 1000,A MOD 1000) x @-3)) ;               0689
             WRITE(PDKOUT,FMT3,AA)  ;                                               0704
END .                                                                    216        0712
                                                              2 IS 715 LONG, NEXT SEG 1
COS IS SEGMENT NUMBER 0004, PRT ADDRESS IS 0061
SIN IS SEGMENT NUMBER 0005, PRT ADDRESS IS 0062
UUTPUT(W) IS SEGMENT NUMBER 0006, PRT ADDRESS IS 0060
BLOCK CONTROL IS SEGMENT NUMBER 0007, PRT ADDRESS IS 0005
ALGOL WRITE   IS SEGMENT NUMBER 0008, PRT ADDRESS IS 0014
ALGOL READ    IS SEGMENT NUMBER 0009, PRT ADDRESS IS 0015
ALGOL SELECT  IS SEGMENT NUMBER 0010, PRT ADDRESS IS 0016

                                                              1 IS  2 LONG, NEXT SEG 0
                                                             11 IS 69 LONG, NEXT SEG 0
```

Table 4. (continued)

```
NUMBER OF ERRORS DETECTED = 0. COMPILATION TIME = 31 SECONDS.
PRT SIZE = 53; TOTAL SEGMENT SIZE = 813 WORDS; DISK SIZE = 34 SEGS; NO. PGM. SEGS = 11
ESTIMATED CORE STORAGE REQUIREMENT = 3564 WORDS.
```

APPENDIX B

Table 5. Regression Analysis Program

```
            BEGIN                                                            00100 B 0000
                                                                      START OF SEGMENT **** 2
COMMENT          BIVARIATE CORRELATION AND REGRESSION ANALYSIS.  THE LONG    00200 B 0000
                 METHOD OF DIFFERENCES FROM THE AVERAGE IS USED              00300 B 0000
                 RATHER THAN THE SHORT-CUT SUM OF SQUARES.  BOTH             00400 B 0000
                 Y = AX + B AND X = A"Y + B" ARE FITTED.  THE LINE MAY BE    00500 B 0000
                 FORCED THROUGH THE ORIGIN ORS020R 5035;                     00600 B 0000
                                                                             00700 B 0000
                                                                             00800 B 0000
            BEGIN                                                            00900 B 0000
INTEGER          J, N, NAME;                                                 01000 B 0000
                                                                      START OF SEGMENT **** 3
                                                                             01100 B 0000
BOOLEAN          S, SWF, SWP;                                                01200 B 0000
                                                                             01300 B 0000
REAL             IJ, DJ, ESTIMATE, RESIDUAL, SUMX, SUMY, SUMXY, SUMX2,       01400 B 0000
                 SUMY2, DXY, DX2, DY2, AVERAGEX, AVERAGEY, DIFFX, DIFFY,     01500 B 0000
                 VARIANCEX, VARIANCEY, SE SA, SB, TA, TB, R2,                01600 B 0000
                 R, A, B, VARIANCE;                                          01700 B 0000
                                                                             01800 B 0000
FILE IN     CARD1, (1,10);                                                   01900 B 0000
                                                                             02000 B 0003
FORMAT IN   CARD2 (X10, 2E20.11),                                            02100 B 0003
                                                                      START OF SEGMENT **** 4
            CARD3 (X10, 415);                                                02200 B 0003
                                                                    4 IS     10 LONG, NEXT SEG 3
                                                                             02300 B 0003
LIST        SIZES (SWF, SWP, NAME, N);                                       02400 B 0003
                                                                             02500 B 0012
FILE OUT PAPER 16(2, 15);                                                    02600 R 0012
                                                                             02700 B 0016
FORMAT OUT  HEAD (X45, "SIMPLE REGRESSION ANALYSIS" / /),                    02800 B 0016
```

Table 5 . (continued)

```
                                                                             START OF SEGMENT **** 5
              FORM (X43, "CASE NO,", I11 // X40, "DATA POINTS", I11 //          02900 B 0016
              X47, "CONSTANT TERM", //),                                        03000 B 0016
              AVERAGEF (X25, "AVERAGE X", E16.8, X10,                           03100 B 0016
              "AVERAGE Y", E16.8, //),                                          03200 B 0016
              VARIANCEF (X25, "VARIANCE X", E16.8, X9,                          03300 B 0016
              "VARIANCE Y", E16.8, //),                                         03400 B 0016
              RF (X10, "CORRELATION COEFFICIENT", E16.8,                        03500 B 0016
              X10, "FRACTION OF VARIANCE REMOVED", E16.8, //),                  03600 B 0016
              HEAD1 (X47, "Y = AX + B" //),                                     03700 B 0016
              AF(X5, "SLOPE", E16.8, X10, "SLOPE ERROR",                        03800 B 0016
              E16.8, X10, "SLOPE T-VALUE", E16.8, //),                          03900 B 0016
              BF ("INTERCEPT", E16.8, X10, "INTERCEPT ERROR", E16.8,            04000 B 0016
              X10, "INTERCEPT T-VALUE", E16.8, //),                             04100 B 0016
              ERRORF (X18, "VARIANCE OF FIT", E16.8, X10,                       04200 B 0016
              "STANDARD ERROR OF ESTIMATE", E16.8, //),                         04300 B 0016
              HEAD2 (X47, "X = AY +B" //),                                      04400 B 0016
              RESIDUALS (// // X23, "INDEPENDENT", X11, "DEPENDENT",            04500 B 0016
              X13, "ESTIMATE", X13, "RESIDUAL" //),                             04600 B 0016
              RESF (X20, 4(E16.8, X5)),                                         04700 B 0016
              FORCE (/ X45, "NO CONSTANT TERM" //),                             04800 B 0016
              TITLE1 (X49, "Y = AX" //),                                        04900 B 0016
              TITLE2 (X49, "X = AY" //),                                        05000 B 0016
                                                                       5 IS  197 LONG, NEXT SEG 3
                                                                                05100 B 0016
LIST          CASE (NAME, N),                                                   05200 B 0016
              AVERAGED (AVERAGEX, AVERAGEY),                                    05300 B 0023
              VARIANCED (VARIANCEX, VARIANCEY),                                 05400 B 0030
              RO (R, R X R),                                                    05500 B 0037
              AD (A, SA, TA),                                                   05600 B 0045
              BO (B, SB, TB),                                                   05700 B 0053
              ERRORO (VARIANCE, SE),                                            05800 B 0061
              RESO (IJ, DJ, ESTIMATE, RESIDUAL),                                05900 B 0068
              RFOO (R, R2);                                                     06000 B 0077
                                                                                06100 B 0084
LABEL         START ;                                                           06200 B 0084
LABEL EOF;                                                                      06201 R 0084
```

Table 5. (continued)

```
                                                                  06300 B 0084
START:  READ (CARD1, CARD3, SIZES)(EOF);                          06400 B 0084
                WRITE (PAPER, HEAD);                              06500 B 0089
                WRITE (PAPER, FORM, CASE);                        06600 B 0092
                SUMX = SUMY = SUMXY = SUMX2 = SUMY2 =             06700 B 0096
                DXY = DX2 = DY2 = 0 ;                             06800 B 0096
                                                                  06900 B 0100
        BEGIN                                                     07000 B 0100
REAL ARRAY      X(0:N), Y(0:N) ;                                  07100 B 0100
                                                            START OF SEGMENT **** 6
                                                                  07200 B 0005
COMMENT         THE PROCEDURE PRINTDIFF COMPUTES THE RESIDUALS AND PRINTS   07300 B 0005
                THEM ALONG WITH THE CORRESPONDING DATE ;          07400 B 0005
                                                                  07500 B 0005
PROCEDURE       PRINTDIFF ;                                       07600 B 0005
        BEGIN                                                     07700 B 0005
                WRITE (PAPER, RESIDUALS) ;                        07800 B 0005
                FOR J = 1 STEP 1 UNTIL N DO                       07900 B 0009
        BEGIN                                                     08000 B 0010
                IF S THEN                                         08100 B 0010
        BEGIN                                                     08200 B 0010
                IJ = X(J) ;      DJ = Y(J)                        08300 B 0010
        END                                                       08400 B 0012
                ELSE                                              08500 B 0012
        BEGIN                                                     08600 B 0012
                IJ = Y(J) ;      DJ = X(J)                        08700 B 0013
        END ;                                                     08800 B 0014
                ESTIMATE = A x IJ + B ;                           08900 B 0015
                RESIDUAL = DJ - ESTIMATE ;                        09000 B 0017
                WRITE (PAPER, RESF, RESO)                         09100 B 0018
        END ;                                                     09200 B 0021
                WRITE (PAPER (PAGE), RESF)                        09300 B 0023
        END PRINTDIFF ;                                           09400 B 0026
                                                                  09500 B 0027
```

Table 5. (continued)

```
REAL    JER1, JER2,SEG1,SEG2 ;                                  09599 R 0027
LIST    DATA (JER1,Jer2,SEG1,SEG2);                             09600 R 0027
                                                                09700 B 0036
LABEL           FORCELINE ;                                     09800 B 0036
                                                                09900 B 0036
FOR J = 1 STEP 1 UNTIL N DO                                     10000 B 0036
        BEGIN                                                   10100 B 0038
READ    (CARD1,/,DATA)(EOF);                                    10200 R 0038
        X(J) - JER1x(10*JER2);                                  10201 R 0042
        Y(J) - SEG1x(10*AUG2);                                  02020 R 0046
                IJ = S(J) :      DJ = U(J)                      10300 B 0050
                SUMX = IJ + SUMX ;                              10400 B 0052
                SUMY = DJ + SUMY ;                              10500 B 0053
                SUMXY = IJ x DJ + SUMXY ;                       10600 B 0054
                SUMX2 = IJ * 2 + SUMX2                          10700 B 0056
                SUMY2 = DJ * 2 + SUMY2                          10800 B 0058
        END ;                                                   10900 B 0062
                AVERAGEX = SUMX / N ;                           11000 B 0062
                AVERAGEY = SUMY / N ;                           11100 B 0063
                WRITE (PAPER, AVERAGEF, AVERAGEO) ;             11200 B 0064
                FOR J - 1 STEP 1 UNTIL N DO                     11300 B 0067
        BEGIN                                                   11400 B 0069
                DIFFX = AVERAGEX = X(J) ;                       11500 B 0069
                DIFFY = AVERAGEY = Y(J) ;                       11600 B 0070
                DXY = DIFFX x DIFFY + DXY ;                     11700 B 0072
                DX2 = DIFFX * 2 + DX2;                          11800 B 0073
                DY2 = DIFFY * 2 + DY2                           11900 B 0075
        END ;                                                   12000 B 0076
                VARIANCEX = DX2 / (N-1) ;                       12100 B 0079
                VARIANCEY = CY2 / (N-1) ;                       12200 B 0081
                WRITE (PAPER, VARIANCE, VARIANCEO) ;            12300 B 0083
                                                                12400 B 0086
COMMENT         COMPUTE THE CORRELATION COEFFICIENT ;           12500 B 0086
                R = DXY / SQRT (DX2 x DY2) ;                    12600 B 0086
```

Table 5. (continued)

```
                     WRITE (PAPER, RF, RO) ;                                      12700 B 0088
                                                                                  12800 B 0091
COMMENT              COMPUTE REGRESSION COEFFICIENTS FOR Y = F(X) AND X = F(Y)    12900 B 0091
                     ALONG WITH OTHER RELATED DATA ;                              13000 B 0091
                     WRITE (PAPER, HEAD1) ;                                       13100 B 0091
                     A = DXY / DX2 ;                                              13200 B 0094
                     B =(SUMY - A x SUMX) / N ;                                   13300 B 0096
                     VARIANCE = (DY2 - A x DXY) / (N-2) ;                         13400 B 0098
                     SE = SQRT (VARIANCE) ;                                       13500 B 0101
                     SA = SE / SQRT (DX2) ;                                       13600 B 0102
                     TA = A / SA ;                                                13700 B 0104
                     WRITE (PAPER, AF, AO) ;                                      13800 B 0105
                     SB = SE x SQRT (SUMX2 / (N x DX2)) ;                         13900 B 0108
                     TB = B/SB ;                                                  14000 B 0111
                     WRITE (PAPER, BF, BO) ;                                      14100 B 0112
                     WRITE (PAPER, ERRORF, ERRORO) ;                              14200 B 0115
                     IF SWP THEN                                                  14300 B 0119
          BEGIN                                                                   14400 B 0119
                     S = TRUE ;      PRINTDIFF                                    14500 B 0119
          END ;                                                                   14600 B 0120
                                                                                  14700 B 0121
                     WRITE (PAPER, HEAD2) ;                                       14800 B 0121
                     A = DXY / DY2 ;                                              14900 B 0124
                     B = (SUMX - A x SUMY) / N ;                                  15000 B 0125
                     VARIANCE - (DX2 - A x DXY) / (N-2) ;                         15100 B 0127
                     SE = SQRT (VARIANCE) ;                                       15200 B 0130
                     SA = SE / SQRT (DY2) ;                                       15300 B 0131
                     TA = A / SA ;                                                15400 B 0133
                     WRITE (PAPER, AF, AO) ;                                      15500 B 0134
                     SB = SE x SQRT (SUMY2 / (N x DY2)) ;                         15600 B 0137
                     TB = B / SB ;                                                15700 B 0140
                     WRITE (PAPER, BF, BO) ;                                      15800 B 0141
                     WRITE (PAPER, ERRORF, ERRORO) ;                              15900 B 0145
                     IF SWP THEN                                                  16000 B 0148
```

Table 5. (continued)

```
        BEGIN                                                   B 0148
              S = FALSE ;          PRINTDIFF                    B 0149
        END ;                                                   B 0149
              IF NOT SWF THEN GO TO START ;                     B 0150
                                                                B 0153
FORCELINE :   WRITE (PAPER, FORCE) ;                            B 0153
              B = R = 0 ;                                       B 0157
              A = SUMXY / SUMX2 ;                               B 0158
              R2 = (A x SUMXY - SUMY x SUMY / N) / DY2 ;        B 0159
              WRITE (PAPER, TITLE1) ;                           B 0162
              WRITE (PAPER, RF, RFOO) ;                         B 0165
              VARIANCE = (SUMY2 - A x SUMXY) / (N-1) ;          B 0169
              SE = SQRT (VARIANCE) ;                            B 0171
              SA = SE / SQRT (SUMX2) ;                          B 0173
              TA = A / SA ;                                     B 0174
              WRITE (PAPER, AF, AO) ;                           B 0176
              WRITE (PAPER, ERRORF, ERRORO) ;                   B 0182
              IF SWP THEN                                       B 0182
        BEGIN                                                   B 0182
              S = TRUE             PRINTDIFF                    B 0183
        END ;                                                   B 0184
                                                                B 0184
              WRITE (PAPER, TITLE2) ;                           B 0184
              A = SUMXY / SUMY2 ;                               B 0187
              R2 = (A x SUMXY - SUMX x SUMX / N) / DX2 ;        B 0188
              WRITE (PAPER, RF, RFOO) ;                         B 0192
              VARIANCE = (SUMX2 - A x SUMXY) / (N-1) ;          B 0195
              SE = SQRT (VARIANCE) ;                            B 0198
              SA = SE / SQRT (SUMY2) ;                          B 0199
              TA = A / SA ;                                     B 0201
              WRITE (PAPER, AF, AO) ;                           B 0202
              WRITE (PAPER, ERRORF, ERRORO) ;                   B 0205
              IF SWP THEN                                       B 0208
        BEGIN                                                   B 0209
              S = FALSE :          PRINTDIFF                    B 0209
```

Table 5. (continued)

```
            END ;                                                            19600 B 0210
            GO TO START                                                      19700 B 0210
        END;                                                                 19800 R 0210
                                                                        6 IS 216 LONG, NEXT SEG 3
    EOF:  END OF BIVARIATE ;                                                 19900 R 0101
                                                                        3 IS 104 LONG, NEST SEG 2
            END.                                                             20000 B 0001
                                                                        2 IS 5 LONG, NEXT SEG 1
EXP IS SEGMENT NUMBER 0007, PRT ADDRESS IS 0125
LN IS SEGMENT NUMBER 0008, PRT ADDRESS IS 0124
SQRT IS SEGMENT NUMBER 0009, PRT ADDRESS IS 0127
OUTPUT (W) IS SEGMENT NUMBER 0010, PRT ADDRESS IS 0005
BLOCK CONTROL IS SEGMENT NUMBER 0012, PRT ADDRESS IS 0111
X TO THE I IS SEGMENT NUMBER 0013, PRT ADDRESS IS 0110
GO TO SOLVER  IS SEGMENT NUMBER 0014, PRT ADDRESS IS 0110
ALGOL WRITE   IS SEGMENT NUMBER 0015, PRT ADDRESS IS 0014
ALGOL READ    IS SEGMENT NUMBER 0016, PRT ADDRESS IS 0015
ALGOL SELECT  IS SEGMENT NUMBER 0017, PRT ADDRESS IS 0016
                                                                        1 IS  2 LONG, NEXT SEG 0
                                                                       18 IS 69 LONG, NEXT SEG 0
NUMBER OF ERRORS DETECTED = 0.  COMPILATION TIME = 117 SECONDS.
PRT SIZE = 91; TOTAL SEGMENT SIZE = 603 WORDS: DISK SIZE = 32 SEGS; NO. PGM. SEGS = 18
ESTIMATED CORE STORAGE REQUIREMENT = 3344 WORDS.
```

APPENDIX C

Glossary of Symbols and Variables

Symbol		Definition
b_{ij}	=	the slope of the line of regression given by $X_i = b_{ij} X_j + C$
handedness	=	the relative work ability of the two hands
n	=	degrees of freedom
N	=	size of a sample
r_{ij}	=	the coefficient of correlation between X_i and X_j
$s_{b_{ij}}$	=	the standard error of the slope b_{ij}
s_{ij}	=	standard error of estimate for regression of X_i on X_j
$t_{b_{ij}}$	=	slope t value
X	=	a variable
X_i	=	the dependent variable
X_j	=	the independent variable
$\overline{X}_i$	=	the mean of the i^{th} variable
X_1	=	handedness, score from Handedness Board Test
X_2	=	hand preference demonstrated in Water Manipulation Test
X_3	=	performance differential
X_4	=	performance rate
X_5	=	eyedness
X_6	=	questionnaire hand preference
X_7	=	temperature in centigrade degrees
X_8	=	age in years
X_9	=	height-weight ratio in inches per pound

SUBJECT ____________________

Do you smoke? ________ Heavily? ________

Do you drink? ________ When last? ______
Remarks:

Did you sleep well last night? _________

Did you get your normal number of hours of sleep? _______

Have you been confronted recently with an emotional problem? _____
Remards:

Have you taken any drugs or medication of any kind in the last 48 hours?__

What drugs? _______________________
Remarks:

Do you wear glasses? _____ Why? _________ Corrected to 20/20? ________
Remarks:

Have you ever had eye surgery? ______

Have you ever had a broken bone? ____ Which one(s)? _________________

Have you ever had a dislocated member? ____ Which one(s)? ____________

Which hand do you use most often? _________
Mother _______________
Father _______________
Brothers_______________
Sisters _______________

Mother's occupation ____________________________________

Father's occupation ____________________________________

Temperature ________

REMARKS;

Figure 15. Sample Data Sheet, Page One

DATA SHEET

SUBJECT ____________________

WATER MANIPULATION TEST

LH ________

RH ________

$$X_2 = \frac{RH - LH}{RH + LH}$$

BOARD TEST

RUN NO.	START POSITION	(1) START	(2) FINISH	(3)=(2)-(1) TOTAL TIME	(4) CONTACT TIME	(4/3) S	
___	R-A	______	______	______	______	______	= S(R)
___	R-B	______	______	______	______	______	= S(R)
___	L-A	______	______	______	______	______	= S(L)
___	L-B	______	______	______	______	______	= S(L)

$$X_2 = \frac{S(L)-S(R)}{S(L)+S(R)} = \_\_\_\_\_\_\_\_\_\_$$

DOT TEST

(1)____. (2)____. (3)____. (4)____ $X_5 = \frac{\#R's-\#L's}{\#R's+\#L's} =$ ____________

CARD TEST

L.H.B.______ L.H.A. ______ $\overline{\text{L.H.}}$ ______

R.H.B.______ R.H.A. ______ $\overline{\text{R.H.}}$ ______

$$X_3 = \frac{\overline{LH} - \overline{RH}}{\overline{LH} + \overline{RH}} = \_\_\_\_\_\_\_\_$$

$$X_4 = \frac{0.50}{MIN(\overline{LH},\overline{RH})} = \_\_\_\_\_\_\_\_$$

QUESTIONNAIRE

A ______

B ______

$$X_6 = \frac{A-B}{13} = \_\_\_\_\_$$

Figure 15. Sample Data Sheet, Page Two

SUBJECT #

Name ______________________________ Age ____ Height __________

Weight _________ Occupation ___________________________________

QUESTIONNAIRE

Answer the following questions carefully. Imagine yourself performing the activity described before answering each question. Answer by drawing a circle around the appropriate set of letters appearing to the left of each question whose meaning is:

RA = right hand always	LA = left hand always
RM = right hand most of the time	LM = left hand most of the time
E = both hands equally often	X = do not know which hand

1.	RA	RM	E	LM	LA	X	:	to hold drinking glass when drinking
2.	RA	RM	E	LM	LA	X	:	to hold knife when cutting food
3.	RA	RM	E	LM	LA	X	:	is used to write with
4.	RA	RM	E	LM	LA	X	:	holds tennis racket when playing
5.	RA	RM	E	LM	LA	X	:	to hold pitcher when pouring out of it
6.	RA	RM	E	LM	LA	X	:	to hold toothbrush when brushing teeth
7.	RA	RM	E	LM	LA	X	:	to throw a ball
8.	RA	RM	E	LM	LA	X	:	to hold scissors when cutting
9.	RA	RM	E	LM	LA	X	:	to hold needle when threading
10.	RA	RM	E	LM	LA	X	:	to hold potato when peeling
11.	RA	RM	E	LM	LA	X	:	to hold dish when wiping
12.	RA	RM	E	LM	LA	X	:	to hold nail when hammering
13.	RA	RM	E	LM	LA	X	:	to hold bottle when removing top

Figure 16. Handedness Questionnaire

Table 6. Raw Data

Subject No.	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9
1	-0.012	0.5	0.354	1.190	0.5	0.769	25	23	0.452
2	0.355	1.0	0.343	1.493	1.0	0.731	25	22	0.400
3	0.212	1.0	0.241	1.075	1.0	0.808	25	23	0.400
4	-0.113	1.0	0.247	1.370	0	0.769	26	23	0.452
5	0.025	1.0	0.228	1.408	0	0.731	26.5	20	0.411
6	0.330	1.0	0.222	1.389	0.5	0.923	26.5	24	0.412
7	-0.020	1.0	-0.292	1.587	1.0	0.923	25	24	0.406
8	0.295	1.0	0.100	1.235	1.0	0.731	25	32	0.436
9	0.192	1.0	0.248	1.031	1.0	0.962	24.5	22	0.496
10	0.038	1.0	0.269	1.389	0.5	0.808	25	21	0.444
11	0.168	0.9	-0.102	1.190	1.0	0.577	25	21	0.429
12	0.215	1.0	0.241	1.250	0	1.0	26	21	9.436
13	0.589	0.3	0.196	1.316	1.0	-0.231	25	21	0.465
14	0.044	1.0	0.208	1.316	-1.0	0.846	26	28	0.336
15	0.113	1.0	0.216	1.515	1.0	0.615	26.5	23	0.496
16	-0.177	-1.0	-0.224	1.010	0	0.346	24	21	0.351
17	0.048	1.0	0.139	1.111	1.0	1.0	25	19	0.292
18	0.232	1.0	0.174	1.449	0.5	0.269	26	23	0.389
19	0.046	1.0	0.088	1.136	1.0	0.615	27	22	0.450
20	0.115	1.0	0.240	1.149	1.0	0.769	25.5	23	0.444
22	-0.033	0.9	0.282	1.351	1.0	0.769	27	21	0.489
24	0.178	1.0	0.222	1.389	1.0	0.962	26	23	0.394
25	0.135	0.6	0.306	1.471	1.0	0.885	27	21	0.515
26	-0.256	-0.9	-0.207	1.136	-1.0	-0.423	27	19	0.425
27	0.176	1.0	0.224	1.316	1.0	0.808	27	20	0.430
28	0.063	1.0	0.217	1.235	1.0	0.923	28	29	0.406
29	-0.306	-0.1	0.117	1.149	1.0	0.231	26	23	0.400
30	0.302	1.0	0.283	1.315	1.0	0.962	26	22	0.370
31	0.184	1.0	0.242	1.332	1.0	0.886	26.5	28	0.378
32	0.225	0.6	0.140	1.300	1.0	0.770	26.5	22	0.430
33	0.058	1.0	0.319	1.615	0.5	0.808	26.5	22	0.336
34	0.303	0.6	-0.118	1.667	-0.5	0.962	25	24	0.458
35	0.279	1.0	0.258	1.315	1.0	0.769	25	24	0.412
36	0.279	0.6	-0.095	1.162	1.0	0.769	26	20	0.405
37	0.380	1.0	0.218	1.454	-1.0	0.962	26	24	0.432
Mean	0.112	0.76	0.165	1.287	0.6	0.691	25.9	22.8	0.421
Variance	0.034	0.28	0.027	0.022	0.42	0.116	0.87	8.65	0.002

Table 7. Summary of Regression Analysis Program Output

Case No.	Correlation Coefficient	Variance of Fit	Slope	Slope Error	Slope t-value
1	0.49639	0.21994	1.4177	0.46855	3.0257
2	0.41255	0.02276	0.3612	0.15074	2.3964
3	0.26255	0.02109	0.2089	0.14510	1.4398
4	0.33100	0.38797	1.1550	0.62231	1.8561
5	0.17648	0.11671	0.3238	0.34133	0.9487
6	0.12694	0.89047	0.6384	0.94279	0.6772
7	0.15106	8.75270	2.3902	2.95580	0.8086
8	0.11071	0.00240	0.0288	0.04896	0.5894
9	0.31747	0.39179	0.3879	0.21896	1.7715
10	0.72649	0.05688	0.4667	0.08343	5.5943
11	0.12925	0.88993	0.2276	0.33000	0.6897
12	0.29068	8.20020	1.6103	1.00170	1.6075
13	0.08226	0.00241	0.0075	0.01719	0.4367
14	0.19701	0.02177	0.1790	0.16836	1.0633
15	0.21257	0.86416	1.2209	1.06060	1.1511
16	0.09022	8.88420	1.6303	3.40070	0.4794
17	0.24545	0.00228	0.0730	0.05453	1.3398
18	0.28151	0.83333	1.7793	1.14610	1.5524
19	0.08503	8.89230	1.6909	3.74410	0.4516
20	0.85454	0.00234	0.0684	0.06084	0.9935
21	0.22526	0.41360	0.4284	0.35016	1.2234
22	0.25774	8.36200	2.2224	1.57440	1.4115
23	-0.08690	0.00241	-0.0123	0.02674	-0.4615

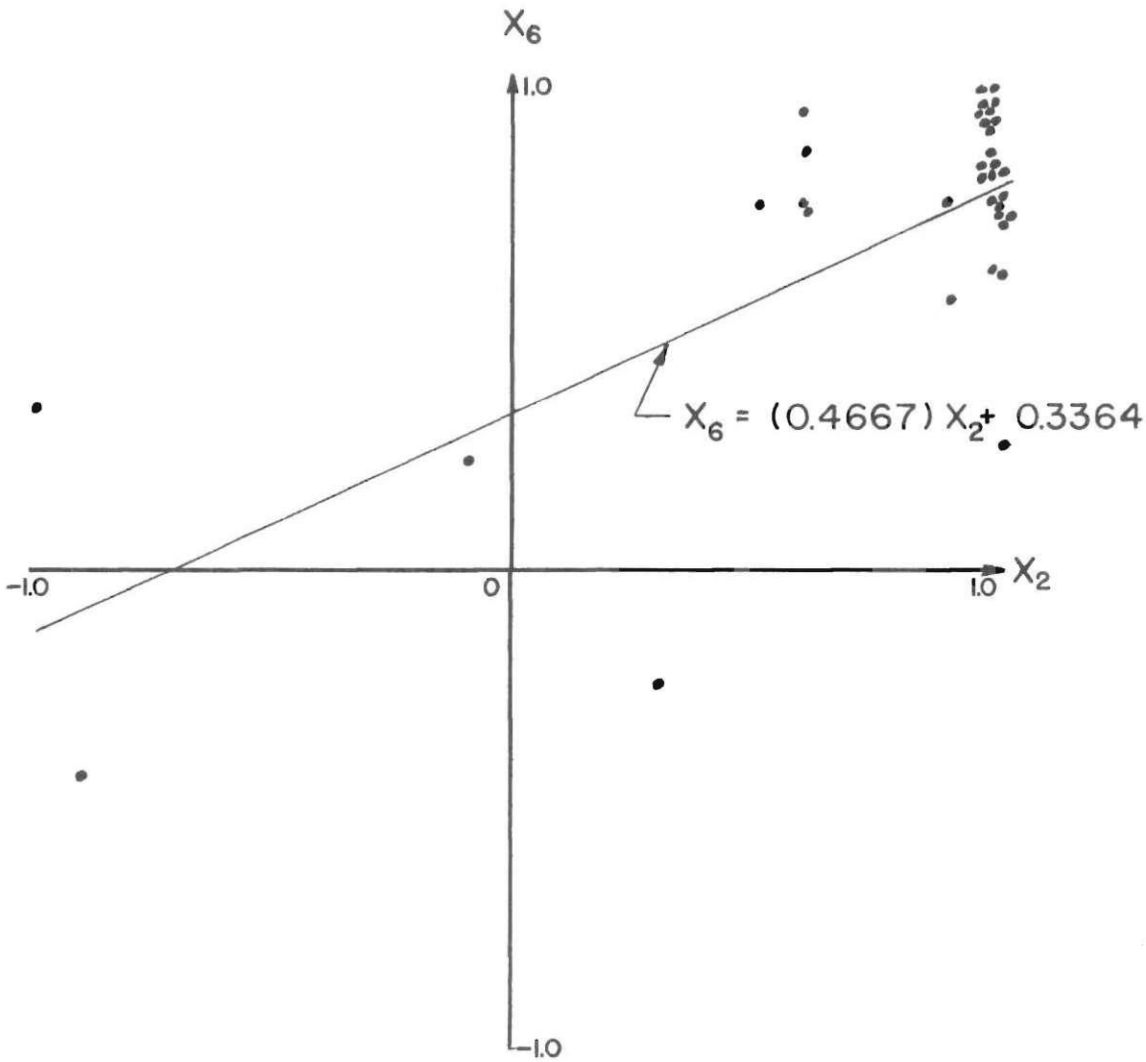

Figure 17. Regression of Questionnaire Hand Preference on Demonstrated Hand Preference

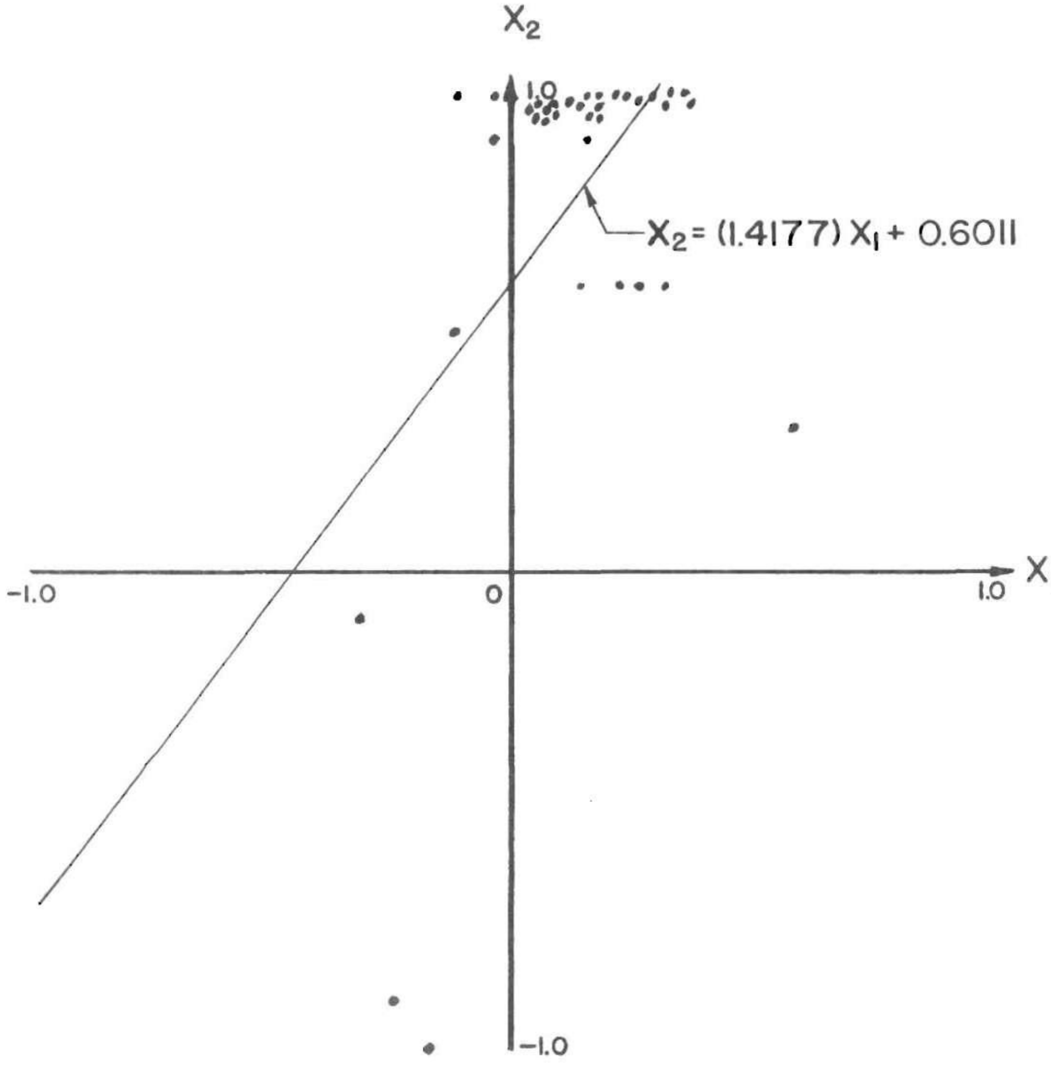

Figure 18. Regression of Demonstrated Hand Preference on the Handedness Board Score

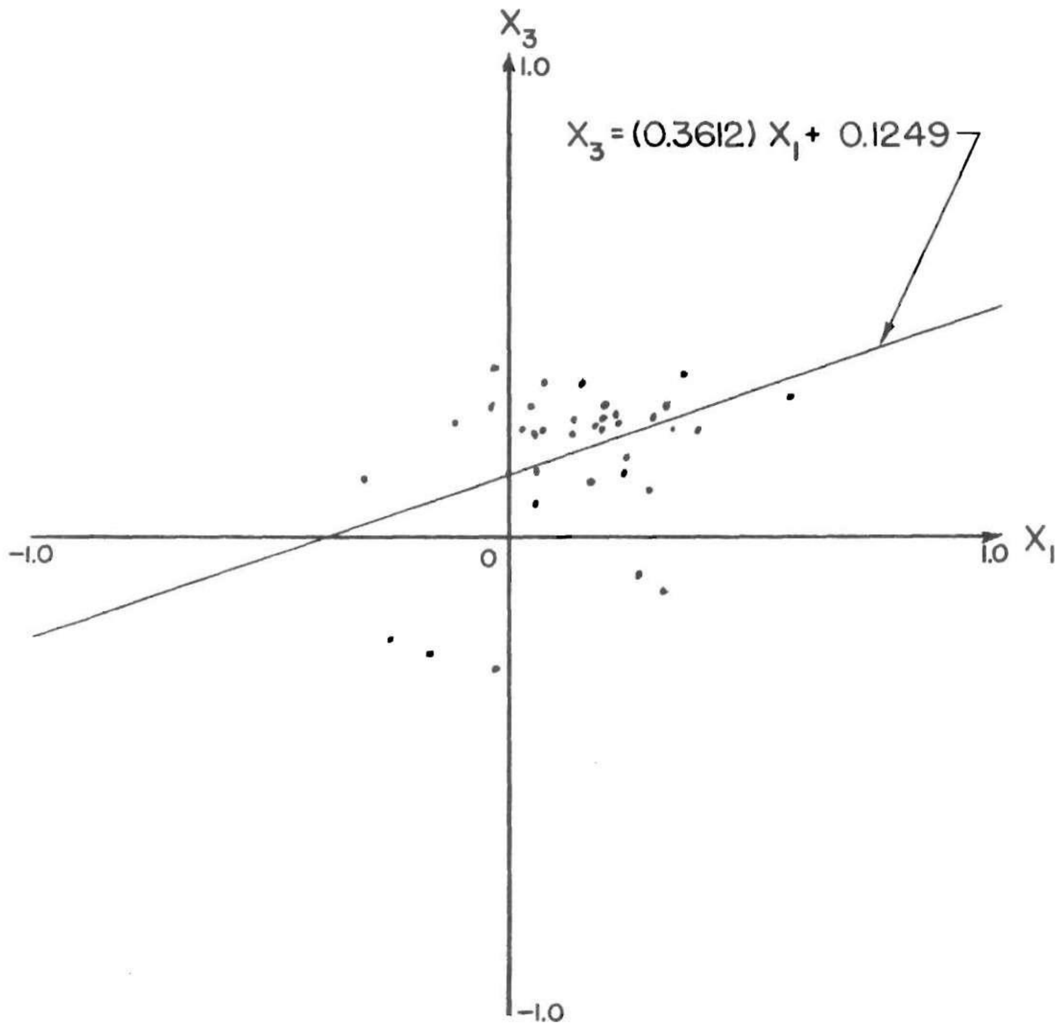

Figure 19. Regression of Job Performance Differential on the Handedness Board Score

BIBLIOGRAPHY

Literature Cited

(1) Ralph M. Barnes, Motion and Time Study, Fourth Edition, John Wiley & Sons, Inc., New York, 1958, Chapter 15.

(2) Ralph M. Barnes, Marvin E. Mundel, and Johnne M. Mackenzie, "Studies of One and Two Handed Work," University of Iowa Studies in Engineering, Bulletin 21, March, 1940.

(3) L. F. Beck, "Manual Skills and the Measurement of Handedness," The Journal of Psychology, Vol. 2, 1936, pp. 359-372.

(4) Douglas E. Bledsoe, "An Investigation of Handedness and Its Relation to Job Performance," an unpublished Special Problem Report, School of Industrial Engineering, Georgia Institute of Technology, June, 1965.

(5) Herbert F. Crovitz and Karl Zener, "A Group-test for Assessing Hand- and Eye-dominance," American Journal of Psychology, Vol. 75, No. 2, 1962, pp. 271-276.

(6) Neil G. Fahrion, "Measurement of Motor Styles," Perceptual and Motor Skills, 1964, Vol. 19, pp. 136-146.

(7) Arthur Falek, "Handedness; A Family Study," The American Journal of Human Genetics, 1959, Vol. 11, pp. 52-62.

(8) Arnold Gesell and Louise B. Ames, "The Development of Handedness," The Journal of Genetic Psychology, 1947, Vol. 70, pp. 155-175.

(9) Gertrude Hildreth, "The Development and Training of Hand Dominance," The Journal of Genetic Psychology, 1949, Vol. 75.

(10) Martin Krampen, "Handedness as a Variable of Importance in Determining Apparent Movement Direction," The Journal of Psychology, 1963, Vol. 56, pp. 61-67.

(11) Earnest J. McCornick, Human Factors Engineering, Second Edition, McGraw-Hill Book Company, Inc., New York, 1964, pp. 362-378.

(12) Robert D. Palmer, "Development of a Differentiated Handedness," Psychological Bulletin, 1964, Vol. 62, No. 4, pp. 257-272.

(13) K. A. Provins, "Handedness and Skill," Quarterly Journal of Experimental Psychology, 1956, Vol. 8, No. 2, pp. 79-95.

(14) J. Richard Simon, "Steadiness, Handedness, and Hand Preference," Perceptual and Motor Skills, 1964, Vol. 18, pp. 203-206, Southern Universities Press, 1965.

Other References

(1) Bayliss, L. E., "Principles of General Physiology," Vol. 2, Fifth Edition, Longmans, Green and Company, Ltd., London, 1960.

(2) Briggs, Peter F., "The Validity of the Porteus Maze Test Completed with the Non-Dominant Hand."

(3) Carlson, Anton J. and Victor Johnson, The Machinery of the Body, Fourth Edition, University of Chicago Press, Chicago, 1953.

(4) Dennis, Wayne, "A Note on Sex Equality in the Incidence of Left-Handedness," Journal of Educational Psychology, Vol. 49, No. 4, 1958, pp. 209-210.

(5) Dennis, Wayne, "Early Graphic Evidence of Dextrality in Man," Perceptual and Motor Skills, 1958, Vol. 8, pp. 147-149.

(6) Fulton, John F., A Textbook of Physiology, Seventeenth Edition, W. B. Saunders Company, Philadelphia, 1955.

(7) Gesell, Arnold and Frances L. Ilg, Child Development, Harper and Brothers Publishers, New York, 1949.

(8) Heilbrun, L. V., An Outline of General Physiology, Third Edition, W. B. Saunders Company, Philadelphia, 1952.

(9) Hildreth, Gertrude, "The Development and Training of Hand Dominance," Part I, Journal of Genetic Psychology, 1949, Vol. 75, pp. 197-220.

(10) Hildreth, Gertrude, "The Development and Training of Hand Dominance," Part II, Journal of Genetic Psychology, 1949, Vol. 75, pp. 221-254.

(11) Hildreth, Gertrude, "The Development and Training of Hand Dominance," Part IV, Journal of Genetic Psychology, 1950, Vol. 76, pp. 39-100.

(12) Hildreth, Gertrude, "The Development and Training of Hand Dominance," Part V, Journal of Genetic Psychology, 1950, Vol. 76.

(13) Holt, S. B., "Genetics of Dermal Ridges: Bilateral Asymmetry in Finger-ridge Counts," Annual Eugenics, 1954, Vol. 18, pp. 211-231.

(14) Margoshee, Adam and Glenn Collins, "Right-Handedness as a Function of Maternal Heartbeat," Perceptual and Motor Skills, 1965, Vol. 20, pp. 443-444.

(15) Murphy, Mary, Martha, "Hand Preferences of Three Diagnostic Groups of Severely Deficient Males," Perceptual and Motor Skills, 1962, Vol. 14, p. 508.

(16) Provins, K. A., "The Effect of Training and Handedness on the Performance of Two Simple Motor Tasks," Quarterly Journal of Experimental Psychology, 1958, Vol. 10, pp. 29-39.

(17) Rife, D. C., "Handedness and Dermatoglyphics in Twins," Human Biology, 1943, Vol. 15, pp. 45-54.